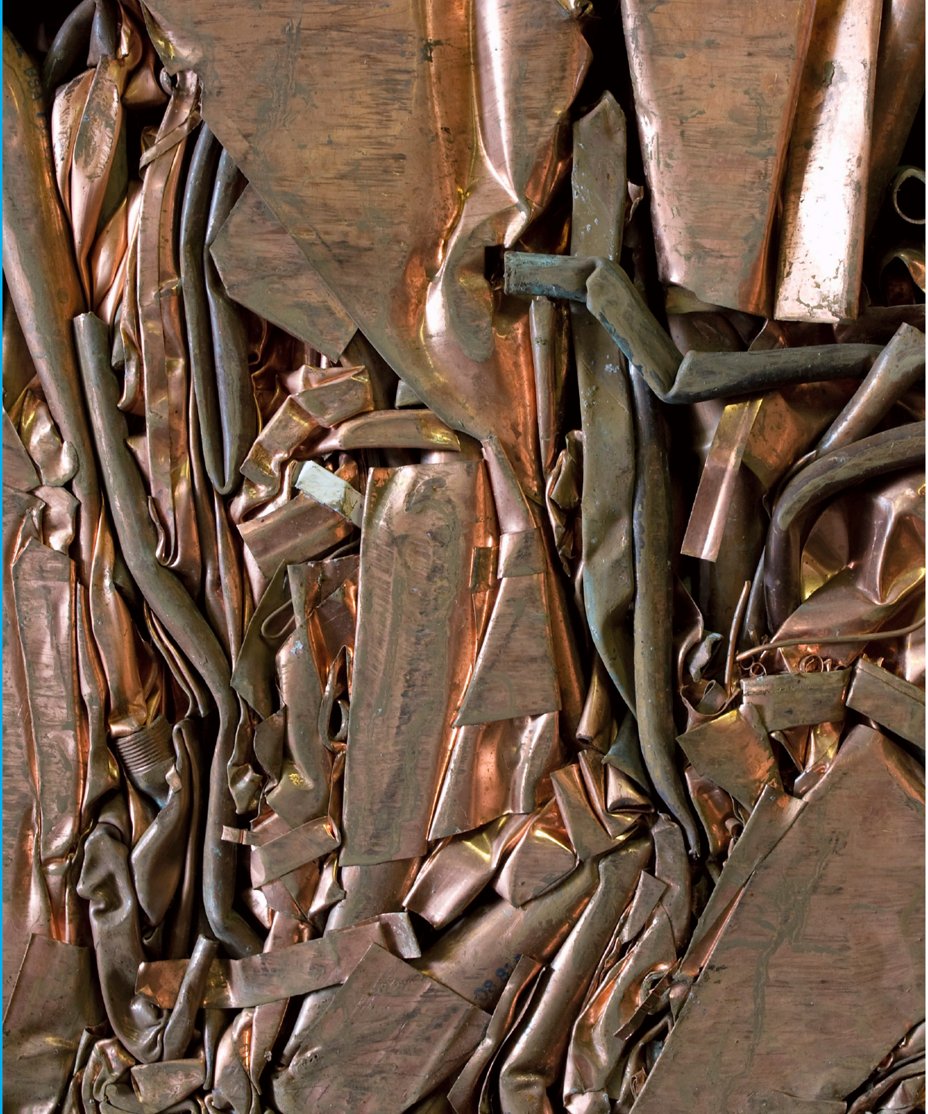

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192

Minerals in Circular Economy – Book of Abstracts

First International Conference on Minerals in the Circular Economy, 26–27 November 2014, Espoo, Finland

VTT TECHNOLOGY 192

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Foreword

The modern society is based on using mineral commodities: their total consumption correlates with economic growth and urbanization. Due to population growth on the global level, the total consumption of mineral raw materials is expected to increase. At the same time, the transition towards a circular economy plays a key role in decreasing per capita consumption of raw materials. For this transition to happen, top class scientific research that allows for knowledge transfer between different segments of the mineral value chain is required. Sustainable mining, enhanced material recovery, better material and product design, and sustainable resource policies are all essential parts of the science to meet the demands of the circular economy.

This book of abstracts presents the themes of the first international research conference on Minerals in the Circular Economy. It covers broadly a significant research area on tools and methods that apply for the whole mineral value chain from the mine to the user and further to recycling. The first section, *Mineral resources and sustainable mining*, addresses the global challenge of finding new mineral deposits also from the greater depths in the Earth's crust as well as developing efficient, and socially and environmentally acceptable mining for demanding environments. In the second section, *Material design and substitution of critical raw materials*, the articles cover substitution of some key mineral raw materials as an essential enabler of the circular economy. The section also discusses issues of the economic importance of critical raw materials in Europe as well as environmental and performance implications of substitution and remanufacturing. Third, the section *Recycling and recovery of valuable raw materials* presents ways to improve recycling rates in the mineral sector through better pre-treatment methods of complex material streams and innovative concepts in hydro and pyro metallurgy as well as in bioprocessing. Fourth, and finally, the section on *Management and policy in the mineral economy* discusses the international and national legal frameworks and policy instruments with regard to mining and minerals. Presentations also assess the social license to operate in different national contexts as well as market conditions for end-of-life products resource efficiency.

Along with this book of abstracts, on behalf of the organizing committee of the Minerals in Circular Economy conference, I would like to thank all the contributors in making the event successful and demonstrating the outstanding level of international research on sustainable use of natural resources.

Olli Salmi
Research Professor, Mineral Economy Programme Manager
VTT Technical Research Centre of Finland

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Keynote presentations

Closing the circle – the (mis)match between policy research and technology development

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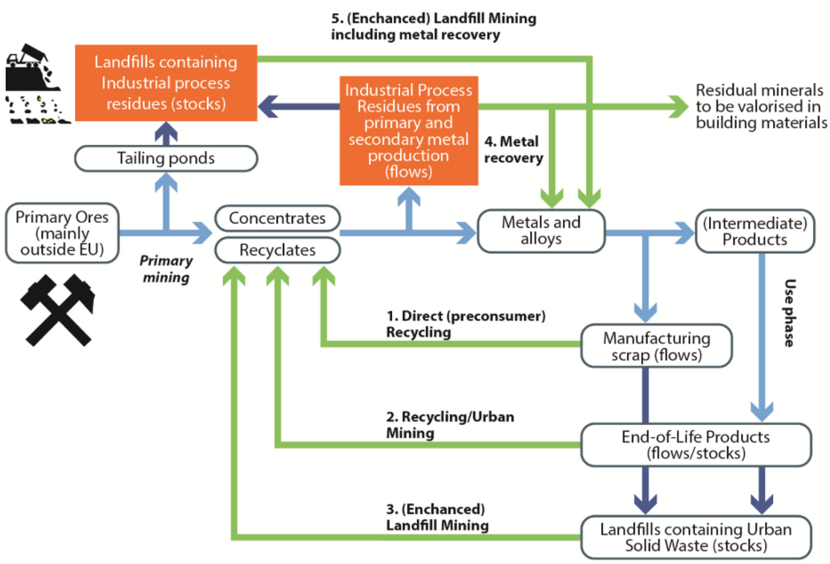
Circular economy encompasses a kaleidoscope of solution directions, all aiming at keeping materials and their value in the economy. As a matter of fact, all future technology developments in mining, recycling and new material and process developments, should take circularity as one of the ultimate goals. Due to technological and thermodynamic limits, this goal is a real challenge. Even if technology or technical solutions are capable of delivering a considerable contribution to circularity, they still have to be economic viable, to be acceptable for society, to be taken up and supported by policy, ... There often is a gap between what policy is striven at and what technology can offer, in both directions. In order to bring technological solutions into practice, the right policy incentives and framework have to be in place. Policy makers also have to know what limits and opportunities technologies represent and what the impact of policy can be on their efficiency and effectiveness, in order to take the right decisions. This lecture will focus on the **interplay between policy research and technological developments in circular economy**, starting from some practical examples.

Closing material loops can be done in many ways (see simplified figure underneath). At the very end of the materials life cycle, the loop could be closed where it has been left open in the past, i.e. by mining landfills. There is a vast, currently still untapped potential of material stocks available in the 150.000 to 500.000 historic and still active landfills in the EU. The idea of **Enhanced Landfill Mining** is to valorize historic and/or future landfilled waste streams as both materials (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE), using innovative transformation technologies and respecting the most stringent social and ecological criteria. Proper technologies and complex process flow sheets have been developed for ELFM. An integrated model has been created for the evaluation of the environmental impact of different scenarios as well as the life cycle cost. This learns technology developers as well as policy makers where the bottlenecks are in implementing ELFM and how the hurdles could be overcome. At the same time, a dialogue with the local community of neighbouring citizens has been set up to learn their concerns and how activities as ELFM can be accepted as a benefit for the society at large as well as for the locals.

A second example is the development of technologies for the **valorization of industrial residues**, such as slags from the metallurgy, or incineration ashes, or sludges, ... Beyond the low hanging fruit of extracting concentrated and the most valuable metals out of some waste streams, there is a large opportunity in valorizing residues which are more dilute. The opportunity lays in the combined extraction of (some) metals together with the valorisation of the mineral fraction into high added-value, low-carbon building materials. Here again, the economic and environmental impact has to be proven before such materials can be introduced in the market. Policy makers also are interested in the potential now and in the future of residue streams. A particular problem is also the impact of very different policies in neighbouring countries, which sometimes have a very contraproductive effect on e.g. valorizing residues.

A third example discusses more general the improved extraction of materials out of the **urban mine**, i.e. all kind of end-of-life products, often with complex composition and dilute content of valuable metals. Models to improve the recycling, remanufacturing and reuse of end-of-life products and the end-of-life design of products have a huge potential effect on the long term. One of the economic instruments in this context is **extended producer responsibility** (EPR). EPR can be implemented in many ways. However, since current EPR schemes typically contain static recycling targets, the potential to be an incentive for green product design, prevention and technological innovation still are suboptimal.

These three examples give some insight in the impact policy research can have on technology developments, at different stages in the material life cycle and with effects on short to long term. The field of circular economy, and technological as well as policy research, however is very complex and broad. The interlinkage of different innovations and policy incentives is extremely important and can only be studied in large consortia or collaboration platforms, such as to be established in the EIT KIC Raw Materials.



Rare earths: indispensable spices of high technology

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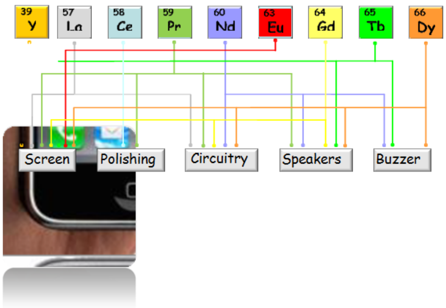
The 17 rare-earth (RE) elements encompassing scandium, yttrium and the lanthanoid series from lanthanum to lutetium have stunning history and properties, which captivated the attention of the most prominent scientists and engineers during the past two centuries.

The main feature of RE elements is their role in high-technology applications while limited amounts only are often required so that the world consumption remains modest, around 120’000 metric tons of equivalent RE oxides per year. The main classes of applications are permanent magnets, catalysts, alloys (in particular the *Mischmetal*), polishing powders, optical glasses, phosphors, and ceramics. The un-matched magnetic and optical properties of these elements make them indispensable in a wealth of high-technology devices such as lasers, optical fibers and amplifiers, military guidance systems, night-vision binoculars, computer and television screens, displays, fluorescent tubes and lamps, light-emitting diodes, security inks and counterfeiting tags including ammunition tracking, electronic components, miniaturized magnets, hard-disk drives, data storage (solid state drives), loudspeakers, windmills, electric bikes and cars, magnetic refrigeration, bio-analyses and bioimaging. In addition, chemical and physical properties of rare-earth compounds are taken advantage of in fluidized-bed catalysts for oil cracking, catalysts for the production of synthetic rubber, automotive catalysts, metal-hydride rechargeable batteries, water purification and filtration sorbents, as well as in polishing powders.



The impact of rare earths on consumer products is illustrated in the following two examples. Neodymium-iron- boron magnets have the largest coercivity of all known magnets; in particular they are used in car loudspeakers which are usually located into the front and/or back doors.

Replacing the miniaturized magnets with iron-based magnets would considerably increase the size of the loudspeakers, necessitating wider and therefore heavier doors; in turn, the car structure would have to be strengthened. All this would result in cars being about 100-150 kg heavier… The second example pertains to smart phones. They contain about 150-250 mg of nine different rare-earth elements which enter into the screen (7 different elements), the buzzer (3 elements), the loudspeaker (5 elements), and the electronic circuitry (5 elements), not to mention powders (mainly cerium oxide) used to polish the screen. Without these elements, the value of which can be estimated to be worth 1-2 US $ only, the smart phones would be much heavier, and far less performing, resembling the 20th century clumsy portable phones.

As an introduction to this lecture, RE properties, resources, mining, separation, and prices will be overviewed, together with a short discussion of the 2010-2012 rare-earth crisis following political tensions between China and Japan. Indeed, China which owns about 30% of the world reserves is producing 90% of all RE oxides used worldwide, at a high environmental cost. To remedy the situation, two large production facilities were started (respectively restarted) in 2012 in Australia and USA; furthermore, Russia is also heavily investing to restore sizeable production by 2018, and more than 50 different mining projects are being presently evaluated outside China. Currently, 5 of the RE elements are classified as "critical", yttrium, neodymium, europium, dysprosium, and terbium. A critical element is defined as any element used in technology that is subject to supply risks and for which there are no easy substitutes (in common language: stuff which is really needed but which is not always available).

As a follow-up, main industrial and scientific applications will be described, with emphasis on luminescence and potential new uses in solar energy conversion, photocatalysis for water splitting, optical refrigeration, luminescence thermometry, and quantum information processing.

The final part of the presentation will evoke recycling policy. In view of both the environmental cost for producing rare earths and a quest for easing the supply market, recycling operations have been recently started, in particular for materials and devices containing substantial amounts of RE, magnets, batteries, or phosphors. Particular attention is also devoted to in-plant recycling of scrap produced during fabrication. However, it is estimated that presently less than 1% of all RE are recycled. Depending on the price of these elements, which has considerably plummeted in 2013 and 2014, it is hoped that anywhere between 10-25% could be recycled in economically viable operations. Alternatively, new technologies provide clues for using less RE elements in applications such as magnets, for instance, or for turning to alternative materials (a difficult task). But despite these prospects, the astonishing and un-matched chemical, magnetic and optical properties of RE compounds will make them unavoidable in future technologies, the only remaining unknown being the amounts required.

Some further reading

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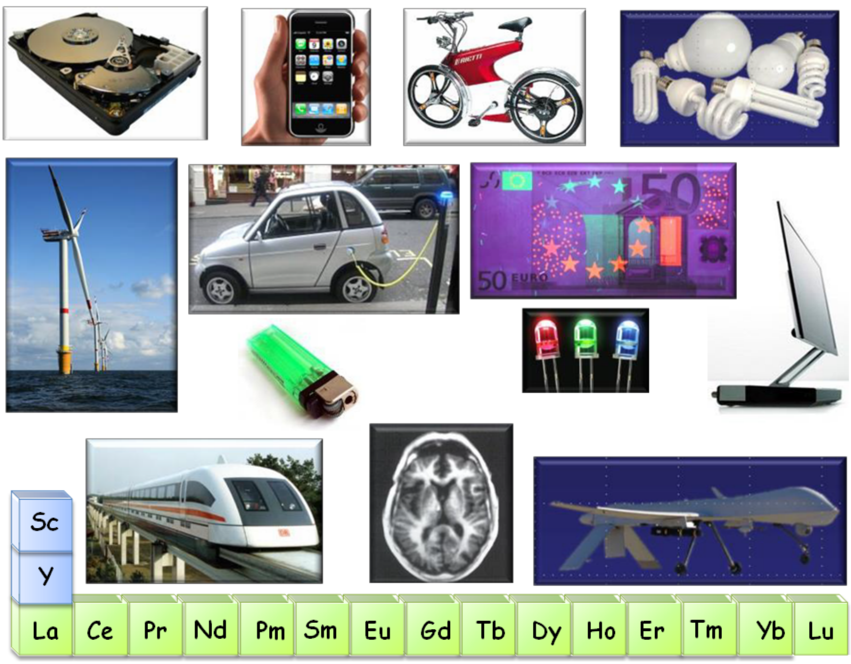

The role of primary minerals in the circular economy

Pekka Nurmi
Geological Survey of Finland, Finland

The unique properties of various ferrous, base and critical minor metals have made them essential constituents of modern high-tech societies. ICT, mobility, energy technology, machinery and infrastructures cannot be developed, maintained or innovated without extensive use of a widening selection of elements. The lifespan of many metal products is long and metals are recyclable in most applications. Therefore, once produced, metals remain available for future generations, and sustainable societies will create effective mechanisms for their recycling and reducing the growing need for primary resources.

The circular economy has no choice, but it will not alone solve the raw materials issue and make it possible to develop a sustainable world economy. By 2050, the world population will rise to 9 billion and 3 billion new people will move to cities. The total consumption of metals and minerals will be considerably higher in future decades, although metal consumption per capita will decrease due to improved resource efficiency, recycling, better product design and new materials.

No rapid breakthrough can be expected in metal recycling. For example, in excess of 80% of iron and copper, which alone account for more than a half of global mining in economic mine value, are already recycled. However, the recycled metals only account for about one-third of present needs for these metals. This is due to the rapidly increased demand during the last decades, and the fact that the average lifetime of iron and copper products is more than 30 years. To meet the growing demand for iron and copper, mining is necessary, but the supply of recycled iron and copper will play a vital and increasing part in the conservation of the finite supply of primary ore, reducing energy consumption and decreasing waste disposal. It is estimated that recycling of iron will meet 70% of the annual demand by the end of the 21st century.

Accelerating technological development based on new innovations will require new raw materials for the next generation low-carbon, hi-tech society. Many of these elements have had only marginal mine production in the past and there is therefore no material to recycle. Recycling of some minor elements can also be technically problematic. It is impossible to provide any exact estimates of the global needs for various mineral raw materials in the next generations. Many hi-tech metals are critical and difficult to substitute, but their consumption compared to ferrous and base metals is small, and their contribution to the global mining tonnage is consequently rather limited.

The mining and metals industry will have a significant role to play in the future sustainable world. The EU is one of the major global users of metals, but is heavily dependent on the import of the metals from increasingly unstable world markets.

There are a number of important operating mines and undeveloped deposits in Europe, and the geology indicates significant potential for discoveries of new ore deposits. Future mining has to be based on resource-efficient technology, automatic processes, high environmental standards, and a shared understanding of economic and social development. Societies, investors and governments will not accept unsustainable mining.

Mineral resources and sustainable mining

The Minerals4EU Knowledge Data Platform for managing Web-based mineral resources information in Europe

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The EU-FP7 project Minerals4EU '*Minerals Intelligent Network for Europe*' is developing an operational data management distributed system based on high-level interoperability standards using advances made in EU-FP7 former projects such as OneGeology-Europe, ProMine and EuroGeoSource, and ongoing projects like EURARE and InGeoCloudS, in terms of database structure, harvesting systems, web services, metadata management, integration of non-structured information and cloud computing. Minerals4EU will also contribute to implement the standards developed jointly by Member States and the European Commission in the framework of the INSPIRE Directive as well as extended domain specifics of a European geoscientific data infrastructure defined in the EU-FP7 EGDI-Scope project. The objective is to develop a Minerals Knowledge Data Platform (the EU-MKDP) allowing to easily combine information related to primary and secondary mineral resources and to provide end-users with all the available information from primary sources to waste streams, from exploration to production and trade, from estimates of resource availability to foresight studies on raw materials supply and demand in the EU. The EU-MKDP will thus represent one of the first bricks of the future European geological data infrastructure. The proposed technical solutions assure an effective and sustainable system designed for facilitating data updates and maintenance, and for giving a full access to information related to the whole mineral resources value chain.

Data related to raw materials, either metallic ores, or industrial minerals or construction materials, of primary origin or from mining and industrial wastes are, most of the time, available in Europe. However, they are often scattered amongst a variety of institutions, including governmental agencies, universities, NGOs and industries. These data are often stored in databases with their own design/architecture and vocabulary, making any attempt of merging in view of a compilation difficult and time consuming. Problems regarding availability, quality, organization, accessibility and sharing of data are common to a number of policies and are experienced across the various levels of public authorities. Solving these problems requires measures that address exchange, sharing, access and use of interoperable spatial data and services both at national and European levels. This is the aim of the INSPIRE Directive (2007, 'establishing an Infrastructure for Spatial Information in the European Community'), but its implementation in the Member States has just started and achieving those objectives represents a major challenge.

In order to create a system that is kept up-to-date, Minerals4EU adopted and developed a distributed architecture based on a central harvesting database synchronized with a central diffusion database. The first one controls the quality of the data coming from the data providers (essentially national and/or regional geological surveys), and the second one is optimized for diffusion, the synchronization between the two databases being made using SQL scripts. The use of central databases allows minimizing the drawbacks of a distributed architecture, improving the performance of the system, and reducing the risk of having actually inaccurate results if local services are down or unreachable. However, not all the knowledge is coming from structured data stored in databases. The system is thus also designed to accommodate semi- and non-structured information (e.g., syntheses and statistics in the form of text, graph charts and time-series, and related to exploration and primary reserves and resources, secondary resources, exploitation technologies including ore beneficiation, extraction technologies, end-product development and waste management practices, European market survey and raw material demand…) in various formats (e.g., Excel spreadsheets, text files, PDF files, images…).

The system must be able to retrieve all pertinent information, spatial and non-spatial, which is related to a topic, becoming thus an incomparable tool for addressing complex questions or problems. This goes through (i) the use of metadata with the development of a specific instance of the MICKA catalogue (used in OneGeology-Europe) for geospatial data and the use of the DUBLIN CORE Metadata Element Set for other data, (ii) the use of a powerful indexation engine which will be able to index the data in the diffusion database, the documents present in the repository and their metadata. Semi- and non-structured information will be processed and indexed, first extracting relevant information from the documents (e.g., named-entity recognition on atomic elements such as names of locations, expressions of time, thematic specific terms…), then classifying this information according to three facets (spatial, temporal and thematic) and creating indexes for each facet and (iii) the development of full-search facilities which will allow the user to search in the diffusion database, in some other databases (manually plugged into the indexation engine) and in documents added to the EU-MKDP using a dedicated interface. The user will be able to search (i) using full text or (ii) using a specific interface dedicated to the concept the user is looking for. Selected data will be sent to the map viewer of the EU-MKDP portal which will allow the user to cross-reference them with other data (geological map, consumption area...). This map viewer will support INSPIRE View Services and will be able to retrieve layers coming from a predefined layers list, a specific instance of the MICKA catalogue dedicated to Minerals4EU, from some other catalogues (One Geology-Europe, INSPIRE...) and external layers (OGC WMS). In addition to that, the portal will offer some dedicated interfaces for different services (statistics, reports...).

Besides continental primary and secondary mineral resources, the EU-MKDP will also manage information related to continental resources at depth and offshore resources. In order to better cover the mineral resources domain, an extension of the platform to urban wastes (WEEE, ELV's and batteries) which represent an important source of secondary critical raw materials has been designed (H2020 ProSUM project recently accepted). From the technical point of view, the foreseen developments bear on domain ontologies which would dramatically improve the power of the search module, the pertinence and the exhaustiveness of the results obtained being the major contribution of a knowledge base. Looking toward the immediate future, the EU-MKDP (i) has been designed to become the core component of the EURMKB (European Union Raw Materials Knowledge Base) that the European Commission aims to get developed rapidly, and (ii) has thus the vocation to accommodate and exploit further datasets.

This presentation describes the activities being undertaken in one of six Work Packages, alongside the establishment of the EU Mineral Intelligence Network, the development of the most comprehensive European Minerals Yearbook and the compilation of a Foresight Study examining issues surrounding minerals supply and demand in Europe. Further information about the project can be found on the website www.minerals4eu.eu.

The Minerals4EU 'Minerals Intelligence Network for Europe' project was funded by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 608921.

Variation in Environmental Impacts of Primary Metal Production

Mark Cooksey[1], Stephen Northey[1], Nawshad Haque[1]
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It is increasingly being recognized that the life cycle impact of products is an important consideration in the transition to a more sustainable society. Companies such as Ford and Apple are reporting and promoting the life cycle impact of their products, often in the form of $CO_{2\text{-}e}$/product. Our objective is for life cycle assessment (LCA) to be used to assist decision-making, e.g. by consumers in purchasing decisions, or by minerals operations when making process technology choices.

Many studies of the life cycle impact of metal products highlight the complexity of system boundaries, co-products, recycling and determining which environmental impacts are important. These studies also recognise that primary metal production is a significant contributor to the overall life cycle impact of metal products. Thus there is great incentive to accurately determine the environmental impacts of primary metal production, and to reduce these impacts. Many metal industry associations have commissioned life cycle inventory (LCI) data collection campaigns to be used in LCA. Initially, the data is collected from individual companies and operations, but then it is usually aggregated for publication, often to global levels. This aggregated data is useful for assessing the overall impact of an industry, but is less useful for decision-making by companies and/or individuals.

Our investigations have shown that the environmental impacts of primary metal production vary significantly between individual operations producing the same metal, up to 1 or even 2 orders of magnitude. For example, we found from a review of annual and sustainability reports by copper producers an energy intensity of 10-70 GJ/t Cu, GHG emissions of 1-9 t $CO_{2\text{-}e}$/t Cu, and water consumption of several kilolitres up to 350 kL/t Cu [1]. This level of variation is not surprising, because of variations in ore grade, mineralogy, processing technology, energy source, local environment and operational performance. This also illustrates the limitations of using aggregated data, as a weighted average or median is unlikely to be representative of a particular operation.

Our objective is to understand the environmental impacts of primary metal production at an individual operation level. This involves decisions on aspects such as system boundary, scopes, input selection, allocation between multiple products, impact category selection, and understanding waste flows.

An example is described for primary aluminium production. We used our process knowledge to determine the most significant inputs to the overall environmental impacts. This is relatively straightforward for aluminium compared to other metals, as almost all alumina is produced by the Bayer process or variations thereof, and all aluminium is produced by the Hall-Héroult process. We augmented Ecoinvent data with publicly available data for individual operations to best estimate the energy intensity and GHG emissions from individual operations. We obtained individual smelter data for the electrolysis intensity (kWh / t Al) and perfluorocarbon (PFC) emissions, and estimated the emissions intensity of the electricity based on regional factors. We used industry average data from the International Aluminium Institute for several inputs (e.g. coke, alumina, gas).

For just the five smelters considered, we found that the energy intensity (MJ / kg Al) and GWP (kg CO_{2-e} / kg Al) varied by factors of 2 and 3 respectively. The range across all smelters will be much higher, because:

- Statistically the range will be larger if more data is included
- None of the five smelters are supplied by coal-fired electricity
- None of the five smelters are in China, and there is evidence that the GWP of alumina production in China is often higher than in the rest of the world [2]
- PFC emissions are often inferred, not directly measured, and there is recent evidence that PFC emissions can occur in situations where previously this was not thought possible.

This simple example illustrates that the environmental impacts of primary metal production are highly variable, so it is difficult to make decisions based on aggregated data.

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Beyond Mine Automation: The Rock Factory and The Common Mine Model

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Mining operations have moved from pre-GFC "Production" to post-GFC "Productivity", which corresponds to a related shift from capital expenditure to capital efficiency. Post-GFC productivity changes are being driven by the convergence of Information and Operational Technologies (IT & OT Convergence).

Traditionally, "Business Improvement" in the mining space has been defined by either incremental or step-change shifts applied to "siloed" operational activities. However, a third transformational improvement has become apparent, which is related to the synergies resulting from the integration of processing and information flows between two or more of these previously "siloed" technologies. By accessing and integrating information from across the value chain, (from the in-situ resource, across mining and processing to marketing and shipping), transformational productivity gains will be realized based on the whole-of-business view, which will allow end-to- end value-chain optimisation.

The Rock Factory (Mark Cutifani, Presentation at the Sydney Mining Club, July 2012) conceptually provides the mine operator with certainty and control of the mining operation in terms of the raw materials (resource model), mining and processing. In the "Rock Factory", the block model is analogous to the "resource warehouse" and the automated drills, haul pack and load-haul-dump loaders are equivalent to the robotics on an assembly line.

In CSIRO's Common Mine Model vision, the resource block model is a mine's most important asset. The information and knowledge it contains regarding both the resource and its surrounding materials is fundamental for future mining, milling, metallurgical and marketing activities. The mine model also impacts regulatory, safety, environmental and even social considerations. In this vision, the resource model is populated with a variety of geochemical, mineralogical, petrophysical, physical, geotechnical, mining and metallurgical processing and performance parameters at various spatial resolutions, which are updated and time-stamped as mining proceeds. Hence, the block model may be used for forward modelling, reconciliation and back-analysis. So as mining proceeds, the uncertainty and risk associated with the resource is reduced. More importantly, the mine block model will be the common, single source of truth about the resource asset.

Numerous vendors have automated solutions for their mining equipment and processing operations; however, these systems tend to be proprietary and traditionally viewed as a company's "competitive advantage". Mining companies have forced multi-vendor collaboration; but these solutions tend to be bespoke and expensive. Issues related to communications, data exchange and interoperability need to be overcome; and industry-wide standards need to evolve. Perhaps the most significant driver for this need for interoperability is the increasing acceptance and use of remote operation control centres and control rooms, and the consequent efficiencies and savings that result from their operation.

In recognition of the lack of industry standards, a number of alliances or partnerships have formed between METS providers to facilitate data and communications exchange between their products. And some companies have attempted to provide solutions that can assimilate data from disparate third party databases and software packages. However for such solutions to be truly effective, they need to be able to update and populate the third party systems and overcome differences in underlying communication protocols, especially for cases requiring peer-to-peer interaction.

In line with the principles behind the Rock Factory concept, uncertainty can be reduced by an enhanced knowledge of the resource, including knowledge of how materials will perform during mining and downstream processing. Control within the Rock Factory will be enhanced by accessing and integrating information from all mining and processing activities, ideally after communication and data standards have been established. And ultimately, transformational productivity gains will be realized by combining an enhanced knowledge of the resource with the improved control of mining and milling systems, and an ability to optimize or tailor all mine activities as a whole-of-business, end-to-end process.

Intelligent Deep Mining in the Future – Current Results of the I²Mine Project

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Economy needs mineral raw materials in almost each sector of modern life. They can only be provided by mining activities. An increasing share of the total mining production will be by underground mining. The mineral deposits will be found in gradually greater depths, including all problems associated with it. It involves an increase in overburden pressure with subsequent rock stability problems and risks of structural collapse. There is a need for new and safe technologies for almost all parts of a modern mine.

The mining industry faces a number of challenges which require technical solutions that encompass the entire network and include the economic, social and environmental issues. The industry needs a new image based on pioneering solutions and a modern structure that can exploit minerals at greater depths and promote both high productivity and safe working conditions.

Funding has been secured from the European Commission for the I²Mine project. Work started in November 2011. This initiative is designed to focus on the technological challenges the mining industry is currently facing including the exploitation of ever deeper deposits and the aspiration for an invisible, safe, zero impact mine. The project comprise a consortium of 27 organisations from 10 European countries.

I²Mine marks the start of a series of development activities aimed at realising the concept of an invisible, zero impact, deep mine. The extractive sector, still seen as being old fashioned and environmentally unfriendly, will show that mineral extraction and processing can be done in a highly innovative and sustainable manner with low impact underground and zero impact above ground.

The concept of I²Mine is to develop innovative methods, technologies, machines and equipment necessary for the efficient exploitation of minerals and disposal of waste, all of which will be carried out underground. This will dramatically reduce the volume of surface transportation of both minerals and waste, minimising above ground installations and reducing the environmental impact.

New eco-efficient technologies will be applied in order to make the entire mining process more efficient and environmentally sound. The concept is for an integrated mine, with the majority of the installations underground, and only the final product will be transported above ground to be shipped to the customer. Production waste will be treated and stored underground and gaseous emissions will be managed underground as far as practical. I²Mine will also focus on ideas and concepts that increase energy efficiency and decrease waste.

The core of the project will be to develop breakthrough technologies for autonomous, highly selective, continuous mineral extraction processes and machinery based on new sensor technologies, face front separation as well as innovative concepts for mass flow management and transportation integrating state of the art technologies. The concept of an invisible, zero impact mine requires a refined process underground that selectively extracts the mineral thereby reducing waste. For this reason, improved extraction machines and near to face processing methods, including backfill procedures, need to be developed. These developments include rock mechanics and ground control solutions, incorporating health, safety and environmental issues.

The presentation will give an overview of the ideas of intelligent future deep mining based on the current results of the I²Mine project

Intelligent integration of mineral processing technologies for sustainable mining waste treatment

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Mintek has over 80 years of experience in the minerals processing industry and has developed extensive expertise in various aspects of mineral processing technologies such as flotation, precipitation, ion exchange and adsorption as well as biological and other technologies used in the mining industry worldwide. This experience and expertise has been embedded into a platform capable of evaluating various integrated applications of these technologies in order to provide effective decision support for the selection of strategies for the mitigation of environmental impacts resulting from the various waste streams from mining operations. Such a holistic approach can be illustrated by considering Acid Mine Drainage (AMD) as an example. This shows how intelligent integration of Mintek and other available technologies can result in not only the effective treatment of the various waste streams, but also the extraction of valuable metals, otherwise toxic to the environment, from these streams to off-set the treatment costs. Furthermore, this paper describes how this approach can be applied to prevent further generation of toxic waste streams such as AMD whilst extracting value.

Dynamic Tensile Strength of Thermally Shocked Balmoral Red Granite

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Geothermal energy has recently attracted a lot of attention because of its great potential as a future source of renewable energy. The benefits of the geothermal energy include global availability, independence of weather and season, and being environmentally friendly. Unfortunately, to reach the required temperature (about 200°C) to produce electricity one has to drill holes as deep as five kilometers, which is an extremely challenging task. Drilling this deep has many practical and scientific challenges; low rate of penetration and rapid wear of drilling tools are among the most notable ones. The problems become bolder especially in the Nordic countries, where the bedrock consists of hard granitoids, schists, and mafic rocks. Percussive drilling is nowadays used to drill deep holes to hard rocks, but it is expensive, time consuming, and not very efficient. In the recent years, thermally assisted drilling has gained attention as a possible method for a faster and more economic technology for drilling of deep holes. The surface of the rock is weakened by a powerful thermal shock just before the impact of the drill. This makes it easier to drill faster with less tool wear. Although this method has been tested in the laboratory scale, it is not commercially readily available, because simply there is not enough scientific and engineering know-how for building of full-scale drill assemblies.

Developing the drilling methods requires detailed understanding of the rock behavior at the drilling conditions. This allows the drilling methods to be tailored for different rock types, temperatures, and depths of the bore hole. Understanding the rock behavior at the drilling conditions requires designing and building of new experimental setups and combining various techniques together as well as numerical simulations and modeling. The Split Hopkinson Pressure Bar (SHPB) devices are typically used for obtaining information about the material behavior at high rates of strain. In the compression SHPB test, the specimen is sandwiched between two pressure bars, called the incident (input) bar and the transmitter (output) bar. A shorter bar, called the striker bar, is impacted to the free end of the incident bar with a predetermined speed provided by a compressed air gun. Optical IR-sensors are used to measure the impact velocity of the striker, which typically varies between 5 and 40 m/s. Two active strain gauges are attached to the incident and transmitter bars, typically at their center points. The strain gauge signals are amplified by a signal conditioner and recorded on a digital oscilloscope. The impact response of the specimen; stress, strain, and strain rate, can be calculated from the time resolved strain gauge signals. The tension strength of a brittle material can be measured using a so-called Brazilian Disc (BD) test. The BD test is a diametrical compression experiment, where a cylindrical sample is compressed along its diameter. This compression generates tension to the center of the sample, and the tensile stress can be calculated based on the geometry of the sample and the diametric loading force. This test can easily be carried out also with the SHPB devices if high loading rates are of interest. The SHPB tests are extremely fast, and therefore it is not possible to observe what happens at every stage of the tests with normal photography techniques. High speed photography can be used to observe the deformation of the sample during the high velocity impact. Digital Image Correlation (DIC) can be used to analyze and quantify the deformation on the surface of the sample by comparing the obtained digital images as a function of time. Combining the SHPB test, high speed photography, and digital image correlation provides a unique opportunity to measure the full field deformation of the sample up to the dynamic failure even for brittle materials such as rocks.

In this study, thermal shocks were applied on Balmoral Red granite samples, and the effect of the thermal shock on tensile strength of the rock was studied using the SHPB device. A flame torch was used to rapidly increase the temperature of the rock surface, and the surface temperature was controlled by simply adjusting the heating time. The preliminary tests were carried out with thermal shocks of 10s, 30s, and 60s. Liquid Penetrant (LP) NDT technique was used before and after the thermal shocks in order to see if the thermal shocks changed the crack patterns on the surface. Fractal dimensions were calculated from the optical images obtained before and after the thermal shocks. The fractal dimensions can be used to assess the surface damage quantitatively, and to compare the complexity of the crack patterns before and the after thermal shocks. After the thermal shocks, the BD tests were carried out using the HSPB. The tests were recorded by Photron SA-X2 high speed cameras and the obtained images were analyzed using the LaVision StrainMaster (Davis) 3D-DIC software.

The optical images clearly indicate that the number of the surface cracks increases with the thermal shock duration. The fractal dimensions of the crack patterns increase during the thermal shocks for each sample indicating that the pattern of cracks after the thermal shock is more complex and contains more interconnected surface cracks. The preliminary BD tests show that the tensile strength of the rock decreases due to the surface cracks created by the thermal shocks. The DIC analysis of the Brazilian disc tests show that the fracture of the sample initiates at the center of the samples or slightly closer to the incident bar contact point. This is followed by crushing of the samples at the both contact points with the stress bars. Although the scientific work is still in progress, the preliminary testing shows that the industrial potential of the thermally assisted drilling methods, i.e., the effect of the surface cracks on the mechanical properties of the rock, can be quantitatively studied with the SHPB method.

Sustainable Long Term Production Scheduling Based on Metal Grade Uncertainty

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Sustainable long term production scheduling based on the uncertainty of metal grade production is a nontrivial process, and an active research area.

In mining, the description and characterisation of a mineral deposit is normally represented by a model of the orebody, which is estimated using the available drill-hole data set. As the information obtained from the drill holes is limited, the orebody model represents some of the most critical sources of technical uncertainty in a mine project operation and consequently in long term production scheduling.

Despite that advanced techniques based on geostatistics, such as Kriging and conditional simulations, have been developed to quantify the orebody uncertainty, there is still a lack of suitable data science tools and processes able to assess and unveil hidden patterns (information) within the mineral reserves, and corresponding metal grade distribution, which could allow mine planners to make better operational decisions, i.e., to generate a sustainable plan and design of the long term production scheduling of the mine project by taking care to not destroy valuable resources today that could be valuable tomorrow.

This paper discusses the benefits of using specialised data science techniques and processes to complement traditional mine production scheduling optimisation techniques aiming to unveil hidden information within the available ore resource/reserve which is then used for making better operational decisions, i.e., towards a sustainable mine plan and design.

To achieve this, the long term production scheduling of an open pit copper mine project is assessed and evaluated under metal (copper) grade uncertainty. The results showed that an important part of applying data science on the mineral resource/reserve data is the formulation of key questions that visualise the mineral resource/reserve from different criteria, all of them aiming to maximise project value. Another important result obtained from the previous assessment was the generation of a risk robust schedule profile that provides new information about the performance of key operational drivers for ore tonnes and metal production, such as the annual average copper and cut-off grades, which are seen to vary because the in situ metal grade uncertainty.

The paper is organised as follows. Section 1 provides an introduction to geological uncertainty and its effect on long term production scheduling. Section 2 defines and introduces the concept of data science applied to mine project evaluation in the face of geological uncertainty. This section also highlights the importance of applying data science as a complement to advanced mine project evaluation optimisation processes resulting in a robust and sustainable long term production scheduling where available resources are managed considering future productions. Section 3 introduces the case study given by the Base-case production scheduling of a copper mine project. Section 4 provides and discusses the results of applying data science on the Base-case study, and Section 5 provides final conclusions and future directions for further research.

ExplOre – European Exploration Project – Digging Deeper

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The most important metal mining districts in the EU are located in the Fennoscandian shield in northern Finland and Sweden, Bergslagen in Sweden, the Variscan Belt of Iberia and the Central European Kupferschiefer mineral belt. These areas account over 80% of the total metal production of EU. The established mining in these areas provides an excellent basis for ExplOre project with the following objectives: 1) improvement of knowledge of mineral systems enriched in critical and high-tech raw materials; 2) establishment of deposit-and belt-scale 2-3-4D geomodels and newly identified deposits; 3) development of new mineralogical, geochemical and geophysical exploration concepts and mineral prospectivity mapping methods; 4) testing of new drilling and real-time data acquisition technologies with reduced environmental footprints and better capacities to predict deep seated ore deposits.

These economically most important metallogenetic belts of the EU have diverse geology with evident potential for different types of mineral resources. The polymetallic ores in these belts are the most feasible sources of critical, high-tech or other economically important metals in the EU. In addition to the variable geology, the special vulnerability of the environment and the glacial sedimentary cover in the Arctic regions of northern Europe, and the thick weathering crust and more densely populated nature of the target areas in the Iberian and Central European belts influence the practice of mineral exploration in different ways. Therefore the new exploration concepts and technologies introduced by the project are optimized and tested on diverse ore types and European areas. Implementation of the project is based on three major areas of action: 1) Research; 2) Technological development and 3) Testing and validating the results of research and development.

Extension of our knowledge of mineral belts to depths of 3-4 km requires further development of high resolution, deeply penetrating seismic and electromagnetic exploration methods and improvement of their interpretation and involvement in integrated modeling methods. The development of new geophysical tools for deep exploration includes the use of virtual sources, noise interferometry and muons to map buried structures. Improving and developing new borehole instrumentation is also necessary. These geophysical survey methods will offer new cost-effective and environmentally sensitive exploration tools by reducing the number of deep drill holes needed to reveal ore hosting structures. Integration of the key parameters of mineral systems into 2D-3D geomodels also necessitates the refinement of field methods for the evaluation of mineralogy and geochemistry in drill cores by improving hyperspectral and portable mineral/chemical analytical tools. The combination of key parameters from geomodels, new data gained from new exploration methods and existing geophysical and geological databases opens up opportunities for the enhancement of conceptual and empirical methods of mineral prospectivity mapping and spatial data mining.

The expected industrial impact of the ExplOre project is to boost mineral exploration by providing new geo-models, prospectivity maps, databases and newly identified deposits for the most important European mineral systems and belts with metallic ores containing critical metals. This is also supported by active collaboration between the largest and most innovative companies that produce most metals in Europe and leading geosciences research institutions. The produced geomodels will support better targeting of new mineral resources at depth, and the new technologies optimized for deep exploration in diverse terrains will enhance the efficiency of exploration by reducing environmental impacts and costs. This expected outcome of the project will also re-shape exploration practices on low-grade and deep-seated mineral resources. The distribution and commercialization of the project´s outcomes among stakeholders of the extractive industry will improve competitiveness of the European exploration and mining.

Testing the results of the project in mineral belts with different geological, environmental and societal challenges of exploration will also support the generalization of know-how and technologies and their potential transfer outside of Europe. The reduced environmental impact of the new technologies and methods developed by the project will promote social acceptance of mining and therefore support further development of the extractive industry in the target areas. Another important societal impact is the securing and extending of job opportunities in those areas of the EU that have a long history and further perspectives of metal mining.

Novel optical measurements for mineral processing control

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The study describes the application of novel optical instrumentation to the ore beneficiation processes. Combined with advanced mill-wide process control, the latest on-line optical instrumentation would enable better control and optimization of the processes, leading to savings in raw material use, chemicals, water and energy. Moreover, the improved process automation would enable optimized process performance and yield.

Feasibility studies for different measurements have been executed in the Oulu Mining School (OMS) mini-pilot beneficiation plant (Figure 1). The mini-pilot plant is set up according to the concentrator plant at the Pyhäsalmi deposit and it includes the comminution section followed by two flotation sections and the dewatering unit. The comminution circuit consists of a rod mill, a ball mill and a spiral. The flotation section contains a conditioner and 8 flotation banks with 4 cells in each unit. The four optical measurement techniques used in this study include

- on-line bubble size measurement in flotation processes,
- on-line moisture content measurement of crushed ore,
- on-line particle size measurement of crushed ore (dry) and
- off-line particle size measurement of grinded ore (wet).

State of the art methods measure the bubble size of the froth on the top of the floatation cell. In this study a technique to measure the bubble size inside the floatation cell is presented, motivated by a clear industrial need for this kind of measurement device. The applied modular imaging probe consists of an illumination unit, a viewing unit and an electronic unit.

On-line bubble size measurement inside froth in flotation processes gives faster response to changes in the process, enabling better process control and yield. In addition, it gives better understanding of bubble behavior in different depths of flotation cells. The performance of the technique was verified in a laboratory batch reactor and in a flotation cell at Oulu Mining School mini-pilot line.

In the mining industry, moisture measurement is very important during mineral processing from mining to the end product. Too dry of a product can result in excess dust in crushing and in handling of the final concentrates. On the other hand, too high moisture content increases transporting and handling costs, which represent a significant portion of the overall treatment price.

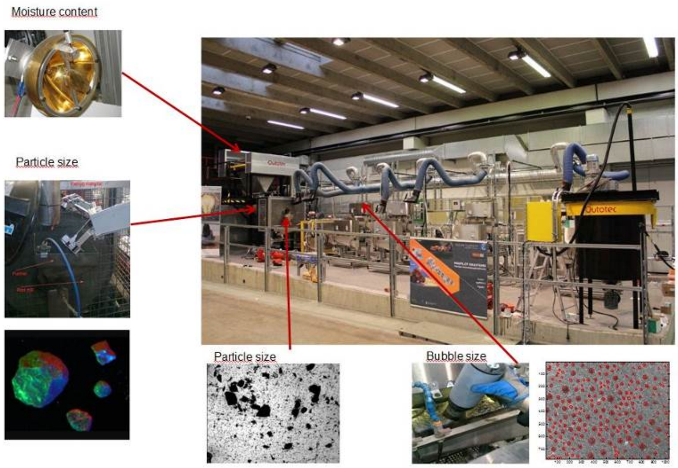

Fig. 1. Oulu Mining School mini-pilot line and developed on-line measurement techniques.

The aim of NIR measurement of crushed ore studied in this project was to develop a fast, reliable on-line moisture measurement for mineral beneficiation control. The laboratory moisture measuring set-up consists of SPECIM SWIR spectral camera and in house built fiber-optic probe. The NIR spectra were acquired from falling mineral crush with different moisture content. It was observed that the water band area correlated linearly with gravimetric method used as a reference.

VTT has developed particle size analyzer for pharmaceutical processes (EyeconTM 3D particle characterizer, Innopharmalabs) for particle sizes 50 – 300 µm. It uses RGB Leds with 1 - 30 µs flash pulse for imaging. The same technology was used for measuring larger particles on mineral processing plants in this study. The particle sizes of dry, crushed ore as well as wet, grinded ore were measured off-line and the dry ones also on-line. The wet samples were imaged with the white led backlight in a transparent cuvette and the camera was in the opposite position. The sample was diluted with water so that the particles were distinguished from each other. The results for dry samples indicate that the particles can be recognized using machine vision algorithm. The method for wet samples seems to have also potential to be cheaper alternative choice to particle sizers based on laser diffraction.

The control of a mineral beneficiation plant is difficult due to the variation of the raw material and lack of the on-line measurements. The proposed measurement techniques could be used to improve flotation control, reduce handling and transportation costs and to increase process knowledge. Further work could focus on developing the proposed bubble size measurement so that particle entrainment could be studied inside the flotation cell. Moreover, an on-line low-cost size measurement for the wet particles could be used to optimise the grinding process, which is the most energy-intensive stage in a mineral concentrator plant. The economic and environmental impacts of the proposed measurements will be studied with the aid of a mineral beneficiation plant simulations.

Role of water in sustainable mining

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Water scarcity and especially the availability of fresh water is a global concern. This has led to an increased need to measure and communicate the impact of water use in water intensive industrial sectors, such as mining. Water sustainability covers the whole value chain, and especially at the corporate level there is a growing need to understand not only the impacts of own processes, but also the role of the supply chain. The mining industry could benefit from the use of water footprint, which is just recently standardised as ISO 14046 Water Footprint – Principles, Recommendations and Guidelines. It is a life-cycle based method to quantify the impacts of direct and indirect water use.

VTT Technical Research Centre in Finland has developed a mining sector specific water footprint approach together with the Finnish mining industry during 2013-2015. The study is done in the Finnish research project 'Sustainable Acceptable Mining' (SAM), where environmental sustainability is focused on water e.g. methodology to assess water footprint for the mine's value chain. The project is part of the ongoing Finnish Green Mining Programme.

The aim of the study was to create a water footprint assessment approach applicable to mining sector in general, following the principles of ISO 14046 and the international methodology development. The presentation outlines two different types of mine case studies representing Finnish open-pit and underground mines at different stages of life cycle. The work was carried out in good co-operation with the mines. The specific needs and challenges regarding building up the framework, the data collection, and the calculation methodology will be presented.

Water footprint increases companies' understanding of the direct and indirect water flows and impacts associated with mine products. Water footprint can be used to benchmark different water related technologies and it helps to mitigate and communicate hotspots where the water use is most critical. Individual companies have taken steps to address issues with increased public attention on water management in mining. Several reporting guidelines exist and are in use within the mining industry. While the Global Reporting Initiative (GRI) offers general reporting guidelines to water disclosure, there is no requirement for quantifying impacts related to water use. Thus, additional tools in reporting such as water footprint can be useful because the mining sector is strongly defined by local solutions and circumstances. Water footprint helps in providing scientifically consistent and reliable information on the impacts of water use in local, regional or national context. It should be a part of environmental sustainability indicator set for any water intensive process industry.

Mines are different and local circumstances vary. Value chain based environmental tools to manage water use and its impacts should be developed further and create guidelines not only to calculate mining sector specific water footprint both on quantity and quality level, but also to include water efficiency and regional water risk assessment. Active research on water management and water accounting in mining sector is being carried out globally. Therefore co-operation between research organisations in different countries is essential. VTT has already created co-operation in SAM project with Fundacion Chile and CSIRO in Australia, serving as a good basis for further joint research work.

Metallogenetic or genetic distribution and resources of industry vitamin (REEs) in Europe

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The demand for Rare Earth Elements (REEs) has grown enormously in recent times as they have become essential for many new technologies and products. Rare earth elements have recently moved to the top of the EU's list of critical raw materials as European companies have focused on supply securing the supplies for their industries. However, it is predicted that the discovery of new deposits will not be enough to meet an increase in demand, as the time lag involved in exploration of new deposits and their eventual production will be about 10 years.

The geology of Europe comprises a broad range of igneous, sedimentary, and metamorphic rocks, in varying tectonic settings and of diverse geological ages, hosting a significant number of REE mineral occurrences. These can be divided into two genetic groups and sources: Primary resources including primary and secondary deposits and Secondary resources.

Primary Resources

This group can be divided to two types of deposits: i) primary deposits, formed through igneous and hydrothermal processes (e.g. carbonatites and/or syenitic rocks, REEs associated with iron oxide and hydrothermal mineralisations); and ii) secondary deposits, concentrated from primary sources by sedimentary processes and/or weathering (e.g. alluvial and fluvial placers, palaeoplacers, lateritic and bauxitic deposits, and ion-adsorption clays). Sweden hosts a large number of known REE occurrences and numerous REE-bearing minerals were originally discovered in Swedish mines and deposits, including Bastnäs and Ytterby in the Bergslagen province and well-know REE mineralisation in Norra kärr and Olserum. Greenland is endowed with several large REE deposits, in various geological settings. The largest deposits are hosted by peralkaline intrusions related to the Gardar Province in South Greenland, encompassing the deposits at Kvanefjeld, Kringlerne, and Motzfeldt Sø. REE deposits are also associated with carbonatites at the margins of the North Atlantic Craton in west Greenland. Finland, located in the central part of Fennoscandian shield, hosts a few sub-economic to economic REE deposits mostly associated with intrusions of alkaline rocks (e.g. Sokli carbonatite and Iivaara ijolite complexes). Norway hosts a variety of REE occurrences, including primary and secondary deposits, typically associated with alkaline igneous and carbonatite magmatic systems (e.g. Fen, Kodal, and others). In southern and central Europe, the extensional and rift systems are less deeply eroded, and potential REE deposits are likely to be buried. Carbonatites in Mesozoic to Cenozoic rifts of Central Europe may well be prospective for REE, whilst secondary deposits associated with alkaline magmatism are of interest in the Mediterranean countries.

The majority of significant primary REE resources in Europe are in alkaline igneous rocks and carbonatites, and the most important deposits occur in extensional rift-related igneous provinces of a range of ages. Each primary deposit has a different, commonly very complex, ore mineralogy and many REE-bearing minerals also have high contents of U and Th. For this reason, each deposit presents its own challenges in processing, and a range of factors will affect the economic and environmental case for the deposit. In Southern Europe, the rift-related provinces are at much shallower levels of erosion, and the surface expression of alkaline magmatism is in alkaline volcanic rocks that do not contain significant REE concentrations. In these areas, secondary deposits formed by weathering (bauxites and laterites) and sedimentary processes are more important. It is likely that primary REE deposits remain to be discovered at depth within these rift zones.

Secondary resources

Secondary resources are those not directly derived from natural REE occurrences, but rather from material that has already been used by humans. Mining wastes, including various waste streams such as weakly mineralized waste rocks, processing tailings and metallurgical residues, could turn out to be potential resources for recovery of exploitable grades of REE. The abandoned historical mine waste dumps in Bastnäs district and the stockpiled apatite Left overs in Kiruna, both in Sweden, as well as the red mud residues of Al smelting in Greece and elsewhere in Europe are prominent examples of raw materials that might be secondary resources of REE.

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Ore Breakage Tests and Process Simulations

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Description of content

The paper describes the (major) achievements and gives an overview some of the tests done in Tekes Green Mining project Energy and Chemicals Saving Flotation Concentration (EnSaCo) and presents the (preliminary) results this far. In EnSaCo-project the energy consumption of concentration process is viewed on the consideration of the ore mineralogy and texture.

Three different ore types, gold ore, silver ore and copper ore, were used in this study. In gold ore the gold exists mainly in tellurides (e.g. calaverite) and slightly as native gold grains. In silver ore silver exists mainly in pyrargyrite, dyscrasite and freibergite and to a lesser extent in metallic form. Characterization of gold and silver ore minerals was done with optical microscopes and Field Emission Scanning Electron Microscope (FE-SEM) and chemical composition was determined with X-Ray Fluorescence (XRF).

Strength properties of gold and silver ore were characterized by different rock mechanical standard tests: Point Load Test (PLT), Impact Crushability Test (Bond CWI), Los Angeles Test (LosA), Abrasiveness and Crushability Test (French Abrasion). One newly established non-standard Geometallurgical Comminution Test (GCT) was also used as well as a uniaxial unconfined compression test. For the uniaxial unconfined compression test gold ore was sawed to geometrically defined blocks and cubes and silver ore drill core was chopped up and halved. This Compression Test was done with Zwick Z100 hydraulic press and very slow compression velocity was used. Simultaneously the acceleration measurement test was also performed. Tracking of the micro cracks which form due to slow compression are identified with micro Computed Tomography (mCT). The ore cube is scanned at full size (at moderate resolution) and mCT analysis can produce large numbers of contiguous parallel cross-sections, allowing 3D visualisation also. The internal structure and composition of ore cubes can be imaged before and after slow compression to determine where and how cracks initiated.

A static and a dynamic flowsheet simulation models were developed for the mini-pilot scale mineral beneficiation plant taken recently into use at University of Oulu, Finland. Currently, the mini-pilot plant is set up according to the concentrator plant at the Pyhäsalmi copper-zinc mine and this set up with copper ore was used in actual mini-pilot test runs to generate data for dynamic simulation model. Simulations are built using the Outotec HSC Chemistry® Sim – Process simulation module. Information of copper ore got from the Outotec Pori Research Center and process description of Pyhäsalmi concentrator plant were also implemented in these models. Dynamic model was tested by simple step test.

Conclusions and significance of the proposed presentation

Comminution of ore is an important process step applied to reduce the size of particles which may have different nature and wide diversity of physical, mechanical and chemical characteristics. In this study mechanical properties of two different ores (gold and silver) were characterized.

Standard rock mechanical tests were done as a reference for newly established GCT and slow velocity Compression test. Moreover the standard test gives, naturally, data which can be used for estimating the wearing rate of comminution equipment. Ore textures were analyzed with microscopying of thin sections and this data can be used for interpreting the compression test results.

Mineral phases (different gray values) and micro cracks (approximately 30 µm in size) was detected from the mCT 3D image of the ore cube. Preliminary results show that the micro cracks appear between dense mineral (bright) and less dense mineral (dark). Thus the slow pressing of the ore may induce micro cracks between minerals.

A static and a dynamic flowsheet simulation models can be used for process optimisation and when designing the future process mini-pilot test works. The simulator also serves as a suitable platform for process development and process design. However, the simulator seems to be valuable in providing insight into the process that is partly quite difficult to measure. As a preliminary result of step test with dynamic simulation model shows a correlation to measured values. As a future work the validation of the created simulation models should be carried out more precisely as soon as next mini-pilot test runs will be done. This static model and its preliminary results are published in IFAC WC 2014 Conference publications under the title ´Pilot Plant Simulation as a Tool for More Efficient Mineral Processing´.

Addressing societal challenges and opportunities through STOICISM: an industrial mineral focused FP7 project

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Europe is a major global producer of industrial minerals. Around 180 million tonnes per year of products are extracted in the EU, with an estimated contribution of €10 billion to European GDP and offering direct employment to some 42,500 people. The growing population and a rapidly increasing demand for water, energy and other resources require innovative solutions for efficient use of these resources and for more sustainable industrial production processes. In addition, it was recognised through the EU Raw Materials Initiative - Meeting our critical needs for growth and jobs in Europe 2020 strategy that there was also a need to improve all raw materials efficiency to remain as self-sufficient and self-sustainable as possible in Europe. To respond to these challenges the industrial mineral sector is pro-active in various initiatives such as: 1. Measure impacts as sector; 2. Provide data along the value chain to downstream sectors; 3. Participate in innovation initiatives 4. Ensure sustainable management of raw materials.

The aim of the FP7 project Sustainable Technologies for Calcined Industrial minerals (STOICISM) is to provide sustainable solutions to one or multiple challenges identified as important by the industrial minerals sector as well as to meet the objectives of the European Innovation Partnership on Raw Materials (EIP-RM). The STOICISM consortium is led by IMERYS a major industrial mineral producing company and consists of 17 partners, from which eight are SME's from 8 different European countries. STOICISM aims to address the whole life cycle from raw material extraction to marketable materials. The industrial minerals covered within the Research Development and Innovation scope of the project are three calcined minerals: 1. diatomaceous earth (DE), 2. perlite and 3. kaolin clay. The results during the first two years of the FP7 project have provided insights on the sustainable identification and extraction practices to maximize yield of the extracted materials through a step wise approach:

- **Geological assessment:** Assessing lithological variations in a deposit through geostatistical simulation is widely used to assess the risk in mineral resources and reserves. Available simulation methods work in fundamentally different manners. In STOICISM, the geological risk relevant for informed mine planning is investigated with two different simulation methods: PluriGaussian Simulation

(PGS) and Sequential Indicator Simulation (SIS). Risk is expressed as a probability of repeated occurrence of lithological units in the same location across simulations. The results provide insights on the type of lithology, its quality and the best suited treatment for a specific end application;

- **Calcination**: Calcination enhances the properties of kaolin ensuring its applicability for a wide variety of products, such as paper, rubber, paint and refractory items. However, mineral processing continues to provide challenges particularly in the area of maintaining efficient process operations. A dynamic model of a multiple hearth kaolin calciner has been developed and is investigated as part of STOICISM. This model describes the physical-chemical phenomena taking place in the six furnace parts: the solid phase, gas phase, walls, cooling air, rabble arms and the central shaft. The solid phase movement, in particular, is described by a novel mixing model.
- **Impurities in kaolin**: Determining iron impurities in calcined kaolin clays through the use of short and long wavelength infrared spectroscopy. The early identification of impurities will assist in adaptation of the techniques for later extraction and beneficiation of the gangue ore to extract kaolin clays adapted to the end market needs;
- **Impurities in diatomaceous earth**: The presence of $CaCO_3$ in diatomite makes diatomaceous earth products chemically reactive, which is undesired for industrial purposes. An adequate mineral processing aiming to control the amount of carbonate requires a precise quantification of the proportion of $CaCO_3$ present in the diatomite ore;
- **Waste as material**: Assess the potential of waste to recover secondary raw materials. The initial assessment indicated that rare earth (Ce, La, Nd) and rare-metal (Nb, Sn, W) have the potential to be concentrated and extracted from the waste generated from the kaolin processing;
- **Life Cycle Assessment**: STOICISM project aims to ensure the overall reduction of environmental footprint and better functionality for specific end use applications. To assess the energy and resource savings the life cycle assessment tool will also be used within the project between the base scenarios versus the innovated calcination technology.

Perspectives and openings for tools to develop processes of Social License to Operate in Finnish mining industry

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Significance of the proposed presentation

The Finnish mining industry started to open up globally in the mid 1990's. It can be argued, however, that mining industry in Finland and the corporate culture largely continued to operate in a national frame of reference, and, consequently, did not undergo the transition that affected the industry globally, characterised by vocal environmental criticism, increasing public scrutiny, and demands for corporate social responsibility. The present challenges are similar to the ones the Finnish forest industry faced in the 80's and 90's, when increasing environmental critique pushed the forest industry for the environmental sake.

The current challenges of the mining industry, sustainability and public acceptance have been addressed as key research topics under the ongoing SAM (Sustainable and Acceptable Mining Industry) research project, funded by the TEKES Green Mining programme. One of the aims of the SAM research project is to understand preconditions and alternatives for improving social licence processes in the mining industry.

Content of the paper

This paper introduces preliminary findings and reflections based on three components of the SAM research project addressing the issues of social licence and public acceptance: 1) customized roadmap process aimed at visioning acceptable mining; 2) two case studies with controversial mining projects, and 3) a benchmarking study comparing earlier transitions in the Finnish forest industry with the current challenges of the mining industry.

First, the drivers and barriers as well as market situation, solutions and enabling technologies in the Finnish mining industry are described as a part of the roadmap process, collecting the data through desk study, interviews and participatory workshop. A vision for an acceptable mining industry was created in this process.

Second, two Finnish mining industry cases are introduced in order to find out concrete and real critical points for developing the process of the social licence to operate in Finnish context. An inventory of 51 mineral exploration companies' web-pages and their social sustainability reporting was also made related to critical points identification.

Third, the results of the benchmark process based on literature and interviews of the Finnish forest industry representatives are introduced.

The special focus in the paper is on the communication processes. Due to distinct differences in opinions even within same stakeholder group, one of our key findings will be addressing the communicational aspects as way to respond the challenges.

Conclusions

In the roadmap process, six vision paths have been identified in a participative foresight process towards a sustainable and acceptable mining in 2030: 1) Development of authority activities, 2) Development of company culture, 3) Life-cycle thinking, 4) Communication, 5) Local acceptability and 6) Creating a learning and creative mining industry. Special indicators indicating the development in these paths, are also identified, e.g. the amount of complaints in permit processes, inherent communication ways or the amount of mapped stakeholders.

The preliminary results of the case-studies indicate conflicting interests, e.g. between mining and tourism industries, and reveal challenges in communication processes between various stakeholders. The project is developing tools to overcome the conflicting dialogue situations in a best possible way. A participatory process for stakeholder groups using a GIS-based web-survey interface (Harava) is tested in the context of the master planning process. The ongoing process points to the importance of careful process design and equitable stakeholder engagement. In addition, a workshop on interaction and dialogue, drawing on methods borrowed from drama and improvisation techniques is planned for studying ways to open up communication patterns that prevent meaningful dialogue from happening.

Communication challenges exist also inside authorities. A common workshop where the regional and state permitting authorities were working together pointed out that there are contradictory values and even misunderstandings among the authorities. Because of such tensions, guidance and steering from different authorities may not be compatible with each other. This situation increases the confusion not only inside the mining companies but also among the public.

The preliminary results of the mineral exploration companies' web-pages and their social sustainability reporting show that many of the companies have not web-site at all, and others only in English and based abroad. Only stock market listed companies present sustainability reporting. A stakeholder engagement framework for mineral exploration has been improved.

In the benchmarking exercise, the conducted interviews and literature research point to the good practises in the forest sector, especially in developing authority routines, corporate culture, stakeholder involvement and communication. The history of the Finnish forest industry shows that structured communication is an important part in creating the trust between stakeholders and industry.

Geoscience Data Transfers Standards: EarthResourceML and GeoSciML, tools to deliver mineral resources data in EU and globally. The EU-MKDP example

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There are two major ongoing interoperability activities applicable in Europe that represents the key pillars of the EU-MKDP architecture (the Minerals Knowledge Data Platform developed in the frame of the EU-FP7 Minerals4EU project). First is the geological community global data exchange standardization activities mainly represented by the GeoSciML (http://www.cgi-iugs.org/tech_collaboration/geosciml.html) and EarthResourceML (http://www.cgi-iugs.org/tech_collaboration/earthResourceML.html) projects organized by the IUGS – Commission for Management and Application of Geoscience Information (IUGS-CGI). The second interoperability pillar is the European legislative/technical framework for building the Spatial Data Infrastructure in Europe (INSPIRE –- http://inspire.ec.europa.eu/) that covers 34 spatial and environmental themes including geology and mineral resources. The legal requirements set up for each of the theme are now being implemented by all EU Member States and some EFTA countries. Both activities are closely related and their data models and harmonized terminology (code lists) are being fully used for the EU-MKDP architecture.

EarthResourceML as well as GeoSciML are the community developed exchange formats for providing detailed information on earth resources including mining wastes as a secondary resource. They both have served as the basis for the INSPIRE Geology / Mineral Resource core data models. For the purpose of the EU-MKDP, both community standard data models will be used to extend the scope and detail of the INSPIRE core data models to address additional requirements mainly from the EU Raw Materials Initiative and the Mining Waste Directive or other EU activities.

GeoSciML is an XML-based data transfer standard for the exchange of digital geoscientific information. It accommodates the representation and description of features typically found on geological maps, as well as being extensible to other geoscience data such as drilling, sampling, and analytical results. GeoSciML provides a standard data structure for a suite of common geologic features (e.g., geologic units, structures, earth materials) and artefacts of geological investigations (e.g., boreholes, specimens, measurements). Supporting objects such as the geological timescale and vocabularies are also provided as linked resources, so that they can be used as classifiers for the primary objects in the GeoSciML standard.

EarthResourceML is an XML-based data transfer standard for the exchange of digital information for mineral occurrences, mines and mining activity. EarthResourceML describes the geological characteristics and setting of mineral occurrences, their contained commodities, and their mineral reserve, resource and endowment. It is also able to describe mines and mining activities, and production of concentrates, refined products, and waste materials.

To facilitate semantic interoperability, the use of controlled vocabularies is embedded in the EU-MKDP data model. The resulting set of code lists and their values is based on the INSPIRE Core Data Models for Geology and Mineral Resources. For the additional vocabulary – not covered by INSPIRE – several interoperability activities and project results have been evaluated.

Taking into account the global aspect of mineral resources (business, protection, scarcity, etc.) the most important activity is the IUGS-CGI work on the EarthResourceML v.2.0 exchange data model. The latest development of the mineral resource terminology has also included the requirements from recent and ongoing EU projects. Currently the EarthResourceML v.2.0 model defines 24 code lists (see http://resource.geosciml.org/static/vocabulary/earthresourceml/2014/).

These geoscience data standards – GeoSciML and EarthResourceML- are used, or are endorsed, as the geoscientific data transfer standard by data sharing initiatives across the world. **The OneGeology** project is currently demonstrating the use of GeoSciML web feature services and GeoSciML-Portrayal web map services in its portal of world-wide geological map data. The inclusion of geology and mineral resources in the European I**NSPIRE** Directive, thus utilising the GeoSciML and EarthResourceML work, facilitates the use of geological and mineral resource information by other thematic communities as well as geoscience data interoperability among countries of the European Union. The EU-FP7 project **Minerals4EU** will contribute to implement these global/INSPIRE geostandards to deliver mineral resource data from 26 EU national geosurveys. The Australian **AuScope** project is using GeoSciML to deliver borehole data from state and territory agencies and EarthResourceML to deliver mineral resource data. The US Geoscience Information Network **(USGIN)** is using GeoSciML-Portrayal and GeoSciML to share geological data between governmental agencies, educational and private institutions. The **Canadian Groundwater Information Network** uses an extension of GeoSciML – GroundwaterML – to integrate water well information from multiple jurisdictions.

The Minerals4EU 'Minerals Intelligence Network for Europe' project was funded by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 608921.

This presentation describes the activities being undertaken in one of six Work Packages, alongside the establishment of the EU Mineral Intelligence Network, the development of the most comprehensive European Minerals Yearbook and the compilation of a Foresight Study examining issues surrounding minerals supply and demand in Europe. Further information about the project can be found on the website www.minerals4eu.eu.

Europe's Rare Earth Deposits, Mineralogy and Beneficiation

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The rare earth elements (REE) are a group of 17 chemically similar metallic elements, including the 15 lanthanides, scandium and yttrium. Among EU launched twenty critical raw materials, REE were among the most important in terms of economic significance and predicted risk of supply because the EU is currently 100% dependent on imports, mainly from China.

The REE are found in a wide range of minerals, including silicates, carbonates, oxides and phosphates. Around 270 minerals are known to contain the REE as an essential part of their crystal structure, but only a small number are ever likely to have commercial significance. The most important are bastnäsite, monazite, and xenotime. The majority of REE production has come from them. Many REE deposits are associated with other REE minerals such as apatite, allanite, parisite and eudialyte etc. REE deposits can typically be divided into primary types, generally formed by igneous or hydrothermal processes, and secondary types in which the REE have been further concentrated through sedimentary processes or weathering.

Europe currently has no mine supply of the REE, but REE resources within Europe have been found. These include peralkaline igneous rocks such as those found in the Gardar Province of south west Greenland and within the Fennoscandian Shield. They also include secondary placer deposits such as those in Greece and Serbia.

Kvanefjeld Deposit in Greenland owned by GME is one of the world's largest known REE deposit. The mineral resource at Kvanefjeld currently stands at 861Mt at 1.06% TREO, and contains 512 Mlbs U_3O_8, 9.22 Mt TREO. Steenstrupine is the major REE mineral. Norra Karr Deposit in Sweden owned by TASMAN holds 331 Kt of TREO at 0.44% TREO with a high HREE/LREE % ratio of 49/51. The major REE mineral is eudialyte. Kringlerne Deposit in Greenland owned by TANBREEZ is a large deposit with the grade of 0.57% TREO and is similar to Norra Karr in mineralogy with the HREE/LREE % ratio of 31/69. Fen complex REE Deposit in Norway located 129 km from Oslo is owned by FEN MINERALS and contains three kinds of ores. The amount of Rodberg ore reaches 300 Mt at over 1.5% TREE grade and up to 76% Fe-oxides grade. In additionally, more than 700,000 t red mud with 0.14% TREO including Sc are produced annually in Greece as by-product of primary aluminium industry.

The EURARE is an EU funded project for the 'Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits'. The main goal is to set the technological basis for the development of a European REE industry that will safeguard the uninterrupted supply of REE raw materials and products to crucial for the EU economy industrial sectors, such as automotive, electronics, machinery and chemicals, in a sustainable, economically viable and environmentally friendly way. The objectives in EURARE include: 1. Definition and assessment of the exploitable REE mineral resources and REE demand in Europe; 2. Development of sustainable and efficient REE ore beneficiation technologies, that will lead to the production of high grade REE concentrates and minimization of produced tailings; 3. Development of sustainable REE extraction and refining technologies, achieving at least 95% extraction and separation yields of REE and to produce at least 98% pure REE oxides, REE metals and REE alloys suitable for use in downstream industries; 4. The development of a strategy for safe REE mining and processing; 5. Field demonstration of the novel EURARE REE exploitation technologies; 6. Identification of novel sustainable exploitation scheme for Europe's REE deposits.

Beneficiation is the term used for the processing of the raw ore to remove gangue minerals, producing a REE concentrate which can then be shipped for further processing. The EURARE project aims to optimize beneficiation for European REE ores and at the same time to minimize the environmental impacts. Beneficiation methods vary from deposit to deposit, and are mainly dependent on the mineralogy, grain-size, and texture of the ore. These characteristics are different for every REE deposit, and therefore the mineralogical studies have to be carried out before beneficiation testing.

Where the minerals in ores are coarse in grain-size they may be possibly concentrated using physical methods such as gravity or magnetic separation. For finer-grained or more complex ores the minerals typically need to be separated using chemical techniques such as flotation or leaching, and a number of different reagents may be used. Extensive testing can be needed to identify the most selective reagents to be used for a particular ore and optimize the conditions.

The first step for the EURARE project was to carry out bench-scale testwork to develop beneficiation flowsheets for several European REE ores. By September 2014, the beneficiation flowsheets had been developed for the ores from Kvanefjeld, Olserum and Norra Kärr deposits, with promising results for the ores from the Fen deposit. The next step is to demonstrate these techniques at pilot-scale at GTK in Finland. The first ore for testing, from Kvanefjeld, had be delivered to GTK in August 2014. Once REE concentrates have been produced, they will be moved to the next step for REE extraction.

As part of the EURARE project, the tailings produced by the beneficiation will be characterized and closely monitored to investigate any potential environmental impacts. In general, the REE tailings do not contain sulphide minerals and therefore do not generate acid mine drainage. Levels of radioactivity are low, but in some cases may be above background.

Material design and substitution of critical raw materials

Integrated Computational Materials Engineering and the Materials Genome – activities at the Hero-M Center

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In order to ensure efficient use of raw materials in industry it is important to be able to design engineering materials to fulfill the performance required by the end user. The concept of integrated computational materials engineering (ICME) has emerged over the last decade as a powerful method to design materials for targeted performance. In a National research Council report (US) ICME is defined as "… the integration of materials information, captured in computational tools, with engineering product performance analysis and manufacturing-process simulation". With materials information is meant curated data sets, structure-property models, processing-structure relationships, physical properties and thermodynamic, kinetic and structural information. To fulfill the need of databases within, models and computational tools within ICME the Materials Genome initiative was announced by US president Obama 2011. Analogously with biological genomes, the materials genome may be defined as a set of information (models and databases) allowing prediction of materials structure and properties as well as their response to processing and usage conditions.

The centre Hero-m was launched at 2007 as a collaborative effort between KTH and Swedish industry with the aim of developing the methods for materials design along the principles of ICME. The center is funded jointly by the Swedish VINNOVA, the industrial partners and KTH and the total budget is ca 200 MSEK over a period of 10 years. The mission is to develop the tools and competence for fast, intelligent and cost efficient materials development for Swedish industry.

The talk will present some of the activities within Hero-m and summarize the situation worldwide on ICME and the materials genome.

Substitution of Critical Raw Materials in high value alloys, super alloys and high T alloys targeting the power generation and aerospace European industry value chains

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The aerospace value chain is facing build rates that are at historical all-time highs and have grown 8.1 percent CAGR since 2008. Aircraft deliveries rose 18 percent in 2012. Goldman Sachs Aerospace analysts expects 6.4 percent growth in 2014, 3.8 percent growth in 2015 and 1.7 percent growth in 2016.

Despite strong demand from the aerospace market, aerospace materials producers face inventory risks. Supply chain "destocking" is seen in almost all areas of the supply chain as suppliers and manufacturers plan for build rate increases, then normalize inventory levels once higher build rates are finalized and the amount of material needed is better understood. This places pressure on spot prices and volumes.

Therefore there is an urgent need for new materials, exhibiting challenging properties at time that avoid or reduce the use of critical raw materials (CRMs).

Special alloys demand is growing and new upgrades are being designed. High strength stainless steels and age-hardenable superalloys are rapidly gaining favor with designers in the aerospace, and other industries who are challenged to meet higher performance expectations and stringent regulatory requirements at lowest life cycle cost. The aerospace industry must achieve superb performance, long term safety, reliability, durability and low life-cycle costs – in short, aircraft that will fly for 30 years with minimal maintenance.

Present target aims to improve with corrosion resistance standard high-strength low-alloy steels (HSLA) while keeping their high strength, toughness, fabricability and damage tolerance.

However, current designs incorporate CRMs to meet the requirements: vanadium, and niobium are added for strengthening purposes. Chromium is added to increase corrosion resistance. Zirconium, and rare earth elements are added for sulfide-inclusion shape control which increases formability.

On the other hand, creep-resistant steels and high-temperature stainless steels are widely used in power generation and petrochemical plants, which use all product forms. Steam turbines require large forgings and castings, whereas pressure vessels, boilers and piping systems require tubes, pipes, plates and fittings. In addition to high creep strength, other material properties like hardenability, corrosion resistance, and weldability are also important, ensuring superior performance across a wide spectrum of high-temperature applications. Improved thermodynamic efficiency is the goal that drives the development of power plant technology, and it requires both improved plant designs and new steels with better properties to support those designs.

While the efficiency of sub-critical plants is less than 40%, future ultra-super-critical (USC) plant efficiency is expected to exceed 50%, cutting CO_2 emissions per kilowatt-hour-produced energy almost in half.

The alloys used in this specific value chain employ the same mechanisms to improve creep strength, the addition of a number of important alloying elements in the steel. Presently significant quantities of Cr and Ce are used, presenting a challenge of substitution in order to avoid raw materials dependence

We present our substitution project aiming to these particular value chains, and incorporate technical alternatives based on Martensitic/Ferritic steels with low content of Nb, V, W, Cr, and other critical elements with same mechanical and creep properties of the conventional Cr-Mo steels nowadays used for high-temperature applications; Oxide-dispersion strengthened (ODS) steels; Nano-structured steels through martensite thermo-mechanical treatment.

EU Critical raw materials in Hungary – a review of a complex research project

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The existence of suitable quantity and quality of raw material is essential for the European economy; EU has recommended the assessment, exploration and evaluation of strategic importance mineral resources in its member states. Priority should be ensured among others to the education for raw material extraction and processing technologies. Raw Materials Group – which was organised under the European Commission – published reports that defined 14 types of raw materials from which Europe may significantly rely on import to the current extraction rates in 2030 and the concentration of whose primary sources involves risk and uncertainties for the EU.

These so called Critical Raw Materials were so far omitted from the mainstream research and exploration efforts, with scarce and unsatisfactory information about their enrichment and extraction potential. Innovation of technological efforts in waste recycling is one of the many important responses that comes from Earth scientists and engineers. An EU co-funded project (CriticEl) has been carried out in Hungary with the main objective of creating basic information about the domestic sources of these raw materials including primary and secondary sources. New rare earth enrichments have been tested in volcanic, metamorphic rocks, fly-ash, red mud. Beryllium and graphite occurrences prospected by geology, geophysics, geochemistry. Indium, gallium, tantalum was searched and tested in different e-wastes.

The paper describes the structure of the research and presents some of the results from the field of both the primary and secondary raw materials.

Substitution with geopolymer materials

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In the EU, production of combustion ashes and ferrous slags is approximately 50 million tons and 45 million tons p.a., respectively and the amount is increasing especially for biomass ashes due to European 20-20-20 targets and increased incineration of sewage sludge. In addition, hundreds of millions tons of mining and quarrying waste is produced annually, which remain without effective utilization in EU.

When aiming towards circular economy, there is an increasing need to develop new, more sustainable production technologies to utilize waste as a substitute for raw materials in different industrial areas. Geopolymer technology is a promising way to utilize aluminum and silicate containing waste materials as a secondary resource in different applications. The most typical application of geopolymers is to use it as a raw material in concrete, where geopolymers appear to be a very promising material since they are an environmentally friendly and technically competitive alternative. Other possibilities to use geopolymers include refractory materials, low temperature ceramics and CMC, fibre-reinforced composites, as well as thermal insulation materials.

This presentation gives and overview on potential use of different mineral secondary resources as a raw material in geopolymers. The first results on the GEOSULF-project are presented. In the GEOSULF-project, the use of sulphide mine tailings in geopolymer materials are studied, with the aim to develop geopolymerization recipes, geopolymer aggregates, and concrete products from sulphide mine tailings. The presentation discusses also possibilities to use geopolymer materials to substitute materials which currently utilizes critical minerals.

Sustainable material design aspects through WC/Co substitution case study

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Sustainable design aspects are discussed through hard metal case study. Raw material scarcity, demand for substitution for critical raw materials, need to substitute toxic materials and need for sustainability are driving to material life cycle design and control evidently. Currently, hard metals (also cemented carbides) are the most important powder metallurgical route manufactured materials widely applied both as bulk materials and as coatings. One of the most common hard metals is tungsten carbide (WC) with cobalt (Co) binder metal, WC/Co. Cemented carbides are preferred materials in applications that must withstand all forms of wear and exhibiting a high degree of toughness. Cemented carbides are primarily used in metal cutting tools, metal forming tools (e.g. dies), construction and mining equipment. In the present list of critical raw materials (7.5.2014) of European Union both tungsten (W) and cobalt (Co) are included containing relative high economic and supply risk. Another very important driver for substitution relates to health. Cobalt is possible carcinogenic material and exposure to cobalt metal dust is most common in the fabrication of tungsten carbide cobalt (WC-Co) hard metal. There is a high pressure to develop cost-effective experimental materials to achieve the mechanical property combination similar to WC/Co in order to create alternatives to the market. The alternative materials to WC/Co carbide material can be based on replacement of the WC carbide, on the replacement of the Co binder or on the replacement of the both components. Besides technological fields also demands concerning ecological aspects create pressure to find substitutes to WC/Co.

We introduce methods for material design to increase of product sustainability concentrating on resource efficiency and environmental aspects. We discuss the potential of newly developed material in substituting WC/Co concentrating on material energy minimization through raw materials, processing and life-time optimization. We also discuss possibilities of material microstructure tailoring for potential substitute through material multiscale modelling. We present a case study demonstrating the use of integrated computational materials engineering for addressing material properties, performance and sustainability. Two example systems are compared against each other, the WC/Co and a candidate to address aspects of sustainability, TiC/Ni. In the cases analysis we present a methodology for a material performance driven design procedure utilizing multiscale modelling, coupling influences arising from processing and performance with respect to the sustainable alternative. We consider interface structures and wetting during material manufacturing, and the following material nano-microstructures with respect to solution properties and performance. The approach exploiting multiscale modelling enables solution driven design utilizing sustainable alternatives by meticulously quantifying the respective influences to material processing as well as performance in an application environment. For hard metals especially wear resistance is important property and using advanced computational modelling and simulation techniques the influencing parameters can be investigated and optimized, the ultimate purpose is to optimize and even control life-time through material multiscale modelling.

Life cycle assessment of process options for FeNi production in Greece

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Ferronickel (FeNi) predominantly originates from nickeliferous laterite ores which are converted into a product with a nickel content of around 20%. With increasing emphasis being put on energy efficiency and global climate change, it is important for the nickel industry to understand in depth the energy use and to evaluate a number of potential opportunities for reducing the greenhouse gas footprint of primary FeNi production.

In this study, the energy and greenhouse gas footprints of the main processes that are used for processing a typical Greek nickel laterite ore have been assessed using Life Cycle Assessment (LCA) methodology. LCA analysis was performed using the GaBi 6 software package and related databases (Figure 1).

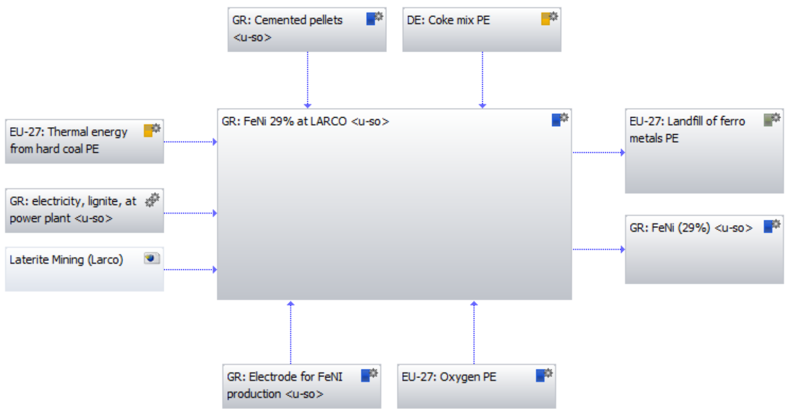

Figure 1. Indicative life cycle diagram for FeNi production at LARCO.

Cradle-to-gate results (including extraction and various processing routes) are presented for high grade ferronickel production, including upstream energy required for fuel production and utilization of raw materials such as coke, lime, cement etc. Using the smelting production scenario as a baseline for processing nickel laterite ore, possible opportunities to improve the energy and greenhouse gas impacts of the various processes for FeNi production, maintain sustainable production and examine alternative ways for waste treatment management (landfill, reuse, recycling) are considered.

The finding of this study underline the need to consider a life cycle approach in the nickel industry by considering energy and climate change concerns in the coming years and through the development of more eco-efficient and cost-effective production processes and technologies.

Relevance of critical raw materials for the European economy – Analysis of energy, transport and ICT and electronics sectors

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This presentation summarises the key results of the supply chain analysis of critical raw materials (CRM) containing applications in energy, ICT and electronics and transport sector. The main aim was to create more understanding about the relevance of CRMs for the European economy and to give indications of which applications could be under threat. The focus was to analyse where in the supply chains the value for Europe is produced and to identify potential CRM related bottlenecks and future opportunities for the EU industry. The study was part of the EU FP7 project CRM_InnoNet (Critical Raw Materials Innovation Network). The results were used in the prioritisation of applications for elaboration of five roadmaps for the substitution of critical raw materials in specific applications.

12 applications from the above mentioned sectors were selected for supply chain analysis based on the assessment of exposure to CRM risk and current economic importance.

- Energy sector: Photovoltaics, wind turbines and energy storage batteries
- ICT and electronics sector: LED lighting, displays and screens, optical fibre, magnetic resonance imaging (MRI), washing machines; printed circuit boards and electronic components
- Transport sector: Automobiles, heavy vehicles and commercial aeroplanes.

The economic analysis of supply chains consisted of the statistical analysis of European production, import, export and jobs over each stage in the production of chosen application. In previous studies these economic aspects have been discussed only superficially. In addition to current economic relevance, it was pointed out how the criticality and vulnerability of the applications are expected to develop in future, and how the potential disruption would affect Europe's ability to meet strategic targets.

The analysis showed that the EU occupies a good position in global production of several target applications with one or more EU companies in the top ten and significant number of jobs in Europe linked to end product manufacturing. It also revealed the future possibilities for market growth. On the other hand, it was found that several economically important applications are exposed to significant CRM issues. Most of the applications are dependent on some essential CRM containing component(s) and materials, which are mainly produced by non-European companies. The analysis of the supply chains enabled also identification of the components that are critical for several economically and strategically relevant applications and thus may need special consideration.

The presentation will also summarise the challenges and opportunities of substitution from the industry point of view based on the industry interviews on current risks and risk provision strategies associated with CRM relevant applications. Despite the challenges it was concluded that Europe may offer feasible environment for development of innovative substitution solutions, which can in several cases be seen as an opportunity for Europe.

Reuse of stabilized fly ash, containing heavy metals, as new raw materials for several applications

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Municipal solid waste (MSW) are one of the major environment problems in many European countries. The European Community has issued directives in order to minimize the disposal of MSW in landfills. Incineration then becomes an effective alternative because it allows a considerable mass and volume reduction of MSW, also allowing an energy recovery. However, residues generated by the incineration plants are potentially dangerous and must be properly treated to avoid secondary pollution.

In the last years, a new process of inertization of fly ash from incineration of MSW has been developed at the University of Brescia. This process, called COSMOS (Colloidal Silica Medium to Obtain Safe inert), was developed as part of a European Union project called COSMOS Project. The method is based on mixing at ambient temperature MSW fly ash, desulphurisation ash of gaseous effluents and coal ash, with a commercial solution of colloidal silica. The research has shown that the inert material has good properties and verified the actual possibility of a re-use as inert / filler in various matrices (polymers, mortars, resins etc..). The colloidal silica is, however, a commercial material and represents the major cost item of the entire process.

Recently this method has been improved substituting commercial colloidal silica, with other amorphous silica sources, as for example, rice husk ash (COSMOS-RICE project). Rice husk (RH) is the natural sheath that forms on rice grain during its growth and it is removed as waste during processing the grains. Since rice is one of the primary sources of food for billions of people, RH is widely available. Rice husk has no commercial value and it is normally combusted openly, thereby causing environmental pollution and disposal problems, or can be used as a fuel. The rice husk ash (RHA) can then be collected as a waste material during the combustion process from the dust collection de-vice in thermal valorization plants. The ashes so obtained contain more than 90% by weight of silica. The amorphous silica required in the process can be easily extracted from RHA through treatment with caustic soda (NaOH) and a subsequent washing with sulfuric acid (H_2SO_4). The obtained gel is characterized by a good purity and high reactivity, thanks to its ultra-fine size and high surface area.

The substitution in the new process of colloidal silica with ashes of rice husk is very advantageous also for sustainability. In fact, no chemicals are involved in the inertization process, but all the reagents are waste materials. From the inertization process an inert product is obtained that may be used as fillers for second hand materials, thus avoiding economic and environmental problems due to storage in landfill.

In this work the preliminary results of the re-use of stabilized materials are shown. The new filler was employed in plastics, resins, ceramics, plasters. COSMOS-RICE was used as filler for Polypropylene (PP) enhancing tensile and flexural elastic moduli if compared with pristine PP. Enhancements of flexural resistance and deflection temperature under load have been observed. This filler may substitute Sb, to improve the fire-resistance characteristic of final composite.

Very promising results have been also obtained in the use of COSMOS-RICE as filler in resin sinks.

COSMOS-RICE also showed unexpected characteristic of dye absorption: it was employed to extract color for example from fruit juice. The adsorptive behavior of COSMOS-RICE is currently under quantification using methylene blue (MB) as dye model compound.

Life cycle methodology to assess Nokia Flexi Mounting Kit's resource efficiency

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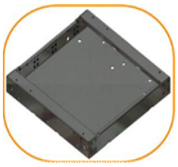
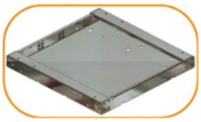
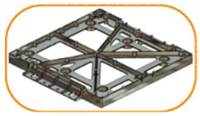
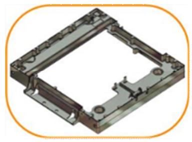
This paper is discussing of the environmental impacts of four versions of Nokia Mounting Kits. Life cycle methodology was used to cover the whole life cycle of the product from raw material acquisition to the end of life. The environmental impact categories included are Global Warming Potential (GWP) and Abiotic Depletion Potential (ADP) including fossil elements in Antimony (Sb) equivalents and fossil fuels in MJ. The object is to assess how resource efficiency has been improved with the evolution of Mounting Kit.

Resource efficiency generally covers three objectives: reducing the environmental impacts, improving resource supply security including lowering import dependency for example for metals, and saving the production costs. The sustainable use of raw materials is widely accepted, but there is no consensus yet how “resource use” should be measured. The measurement can be made based on definition of physical indices like mass and material input per service unit or impact assessment indicators of LCA, like Resource Depletion Potential (fossil fuel or minerals). From life cycle based resource efficiency point of view Design for Resource Efficiency (DfRE) approaches are not today always sustainable, because they only look output emissions released of the product system or the scrap at the end of life stage. From resource efficiency perspective it is necessary to look also at the input side and assess how much natural resources are used and for example recycled material content, which means how much secondary materials actually replace primary materials when the material is manufactured. When metals are recycled, there is a clear reduction in environmental impacts because the demand for primary metals decreases.

In this study resource efficiency is assessed of the evolution of of radio base station mounting kits (four versions). The materials used in these mounting kits are sheet stainless steel, sheet aluminum and sheet stainless steel, and die cast aluminium with small amount of sheet stainless steel. The amount of materials used in the mounting kits was reduced from 6.7 kg to 2.8 kg, and stainless steel sheet metal was replaced by die cast aluminum with optimized design. So, the material and manufacturing method is changed.

Table 1: Improvement history of mounting kit.

Version of Mounting kit	First generation (101-102) 	Second generation (103) 	Third generation (104-105) 	Fourth generation (206) 
Manufacturing technology	Stainless steel sheet	Al sheet with stainless steel sheet parts	Al die cast	Al die cast
Stainless steel	6720	1550	110	110
Aluminium	-	3071	4120	2720

The life cycle CO_2 equivalent emissions of the four version of mounting kits have been reduced from $34kgCO_{2eq}$ to $13kgCO_{2eq}$ accordingly. The second generation mounting kit has the biggest environmental impact in categories of GWP and ADP (fossil fuels), meanwhile fourth generation mounting kit has smallest environmental impact in the same categories. Second generation mounting kit is made mainly of aluminium sheet, and it was assumed to be produced of 100% of primary aluminium. The energy consumption of primary aluminium production is high (95%) compared to secondary aluminium (5%).

In assessing ADP (elements) the characterisation factors were applied to metal weights on bill of materials of mounting kits. Accordingly to this study, the first generation mounting kit made of stainless steel sheet has clearly the biggest impact and the last two generations mounting kits lowest ones. In the third and fourth generation mounting kits the material is mainly die cast aluminium, 100% of which is secondary aluminium. The recycling credit of metals included is in all the cases based on open loop principle.

A sensitivity analysis was done to define the effect on GWP and ADP (fossil fuels), when the production place of third and fourth generation mounting kits changes from China to Finland. According to this study the production of die casting of aluminium in Finland has significantly smaller environmental impact compared to production in China, which is mainly due to the different energy mix.

When focusing on resource efficiency and developing material variety it is necessary to define and assess the environmental impacts of the whole life cycle of products, and not only the environmental impacts of manufacturing the materials. Global warming potential, which is measure of greenhouse gas emission, is generally used as environmental impact category. Other environmental impacts categories should also be applied as measure of natural resources usage. Abiotic depletion potential (elements and fuels) is developed as measure of the usage of natural resources. Its usage has been increased, but still the results are not so reliable than with global warming potential, because the methodology is still in development stage.

Sustainability aspects in remanufacturing

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This paper is discussing of sustainable aspects of remanufacturing and is based on work done in DemaNET-project (Dematerialization and Sustainable Competitiveness through New Models for Industrial Networking). This project belongs to Green Growth program of Tekes.

Remanufacturing is well known only in specific industrial fields and few geographical areas. Remanufacturing is a form of a product recovery process. Remanufacturing is an industrial process in which used products are restored to "like new" condition. This means that the remanufacturers claim that the remanufactured product or component should meet the specifications of a new product or component, both in performance and appearance. Thus a remanufactured product should match at least the same quality standards and customer expectation as a new corresponding product. Remanufacturing is the process of disassembly and recovery at the component level. It involves the repair or replacement of worn out components. Remanufacturing is recycling by manufacturing "good as new" products from used products.

Life cycle methodology can applied to remanufacturing with two life cycles, see Figure 1:

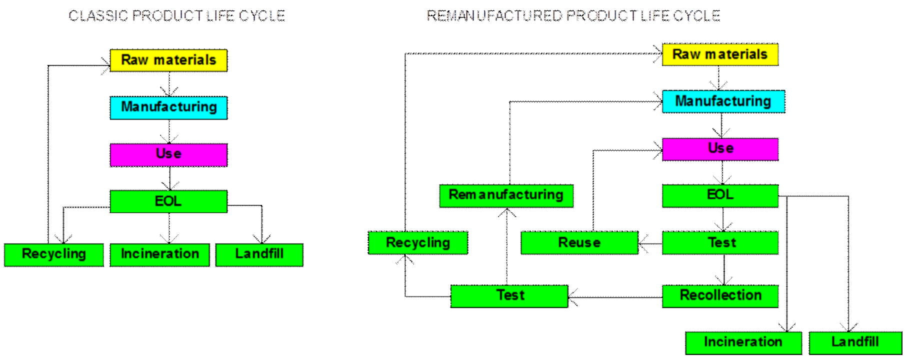

Figure 1. Life cycle material flows for classic and remanufactured products. Classic product life cycle (= two new products), Remanufactured product life cycle (= one new product + one remanufactured product).

Main differences of remanufacturing versus recycling are the lower environmental impacts of remanufacturing when material melting is avoided. Another important issue in remanufacturing is that it prevents contamination of non-wanted elements of materials which would be the case with normal multimaterial recycling process. According to literature the environmental benefits are much higher if a product is designed to be remanufactured and for modularity. This supports the argument that design plays a key role in determining economic and environmental benefits of remanufacturing.

Based on the query accomplished to Finnish companies:

- 17% of the companies say that remanufacturing is shown in their responsibility reports
- 68% of the companies say that reduction of the environmental impacts is one of the most important factors for remanufacturing
- 58% of the companies say that new environmental legislation did not influence to the decisions towards remanufacturing, but 42% say that they are not sure or they don't know.

Remanufacturing is one form of circular economy. Remanufacturing can help the environment in a number of different ways. It saves natural resources, both energy and materials, and reduces the amount of waste and the needed space for waste landfill. Parts are kept out of the recycling and remelting processes longer because of remanufacturing. This leads to savings in oil and other forms of energy consumption. Remanufacturing gives a product several lives instead of just one, thereby saving raw materials. As a consequence of the material and energy savings carbon dioxide and other emissions are lower.

Remanufacturing can be supported by enhancing the awareness of consumers, to enable the consideration of both price and environmental impacts in their decision making process. Warranty can be seen as one of the key social indicators of a remanufactured product. The warranty of remanufactured product is proposed to maintain the performance of the product to be as good as new, which offers a social benefit to the customer. Employment is another important social indicator because a higher regional employment. Jobs in remanufacturing business are desired and most experienced staff is required for the jobs. Today sustainable issues are highly valued by young people. Young generation businessmen think highly of sustainability issues, and money is not the only or prime value for them.

In the future public policies should encourage remanufacturing. E.g. End of Life Vehicle (ELV) -directive does not include remanufacturing as a term in spite of the fact that this directive determines how recyclability and recoverability rates are calculated with vehicles. Thus, to include remanufacturing in the ELV Directive's calculation method would drive manufacturers to think and to apply remanufacturing.

Digital design and systems engineering in circular economy

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There will be increasing need to optimise raw materials flow in the future society due to lack of some critical elements as well as general requirements for materials and energy efficiency. Circular economy is the way to describe these ambitious targets where in the context of mineral economy the design of the product is playing actually very important role.

In design phase many important issues are decided such as what raw materials will be used, how long life time for the product or component is planned and how easy this product or some single elements within it is to recycle.

Digital tools to understand phenomena's and interactions have been developed greatly within last decade. This is mainly caused by the increase of understanding as well as increase of computing power. New modelling and simulation tools for different parts of materials life cycle have been developed. However there is still some way to go to make these tools accurate enough, link their interfaces together, and to create easy user interface for a new users such designers or even consumers. In our visions target has to be digital, systemic engineering tools for circular economy. In this ambitious target raw materials community has very important part.

Application oriented wear testing enables sustainable material solutions

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The scientific understanding of the wear phenomena and wear mechanisms is the basis for sustainable material solutions. In challenging conditions, like in mining and mineral processing, material selection for wear parts has a marked impact on energy and cost efficiency. Earlier studies have shown that various laboratory test methods are needed to properly cover the testing for these severe conditions. Moreover, the test parameters should be selected to be as close to in-service conditions as possible.

In this study, a comparison was made of the wear behavior produced by four different test methods: a crushing pin-on-disc, a uniaxial crusher, an impeller-tumbler impact-abrasion tester, and a high-speed slurry pot tester. The test devices were designed to simulate the end-user applications with high-stress abrasive, impact abrasive or slurry erosion systems. The key design features included selected contact modes, high loads, and varying abrasive types and sizes, which were close to the in-service gravel. Three quenched ultra-high strength steels and a structural steel were tested and characterized. Granite was used as an abrasive.

The crushing pin-on-disc and the uniaxial crusher simulate mineral crushing and handling applications. In the crushing pin-on-disc test, a sample pin was cyclically pressed against a rotating gravel bed with a 240 N constant force. The wear surfaces had long and deep scratches and also contained embedded granite.

The uniaxial crusher crushes gravel with 53 kN force against a stationary counterpart. It produces higher loads than the crushing pin-on-disc, but there is no sliding movement. The wear surfaces were heavily deformed. In addition, the large granite particles caused severe material loss in the structural steel.

The impeller-tumbler type impact-abrasion wear testing equipment was designed to simulate especially the wear of the edge parts of earth moving machinery and in impactor plants. The samples are attached to the holder as impellers, which rotate at a high speed inside a drum filled with gravel. The sample angle, the rotating velocities of the impeller and the tumbler, and the amount, size and grade of the abrasive can be varied. The impacting abrasives deform surfaces heavily, but the relative wear rates (g/h m^2) were the lowest of the studied four methods. However, it should be noted that in the rotating system the impact energies and thus the wear rates are much higher near the tip of the sample than closer to the sample holder.

With the high speed slurry-pot type erosion tester it is possible to achieve high speeds with large abrasive size for simulating slurry pump, dredging, and mineral processing conditions. This method is applicable for a wide variety of materials, including different types of steels, elastomers, and coatings, because the sample size and shape are variable. The studied steel samples were plates, which rotated in a 9% slurry concentration at 1500 RPM. Especially the structural steel rounded heavily from the edges, just like in the impeller tumbler. However, the higher speeds comminuted the granite very efficiently and the relative wear rates were the highest. The particles also slid more and produced clear scratches on the surface.

It can be concluded that all the used test methods produced clear differences between the materials and arranged them with the hardness. During the tests, large natural rock abrasives comminute in a similar manner as in the in-service conditions. However, the contact conditions are different, which is seen from the wear surfaces and the cross-sections of the tested samples. Thus, together these application oriented test methods enable reliable laboratory tests that simulate well various in-service conditions.

Up-grading of Wastes – Elkem Technology as your Technology Partner

Jorunn Voje
Elkem AS Technology, Norway

Elkem is one of the world´s leading companies for environment-friendly production of metals and materials. The main products are silicon, solar grade silicon, special alloys for the foundry industry, microsilica and carbon.

Elkem´s main office is in Oslo, Norway and there are production sites all over the world - in China, Brazil, Canada, South Africa, Island and Norway. Likewise there are sales and marketing offices in all corners of the world. Elkem ´s centre for corporate R&D, Elkem AS Technology, is located in Kristiansand in Norway with approximately 100 employees. The R&D centre has facilities for doing lab scale and larger scale melting trials and testings of raw materials together with a well-equipped laboratory for chemical analyses and material characterization.

Today, the world faces significant environmental and energy problems together with an increasing lack in raw materials. There is not yet a satisfactory solution to these problems. However, recovery of w**aste** materials is one important way of dealing with this.

Elkem with its long lasting experience and competence within high-temperature metallurgical processes is a natural partner in such kind of projects. Elkem has a large portfolio of pyro metallurgical and hydro metallurgical equipment and experience in up-grading of bi-products, testing of raw materials, testing of equipment, process development and verification and product development and - testing.

A typical project is “Re- melting of off- grades in the silicon industry”. Each year about 12% of the Si produced is degraded due to spilling during tapping, raking and refining in a traditional Si- furnace. Elkem Technology has developed a process for slag treatment and metal- slag separation of these off- grades to produce a high purity Si product at low cost. Another project is “Spent pot lining recycling (SPL)”. Spent pot lining from the Al industry is considered a hazardous waste, primarily due to its high content of F along with high K and Na contents. Elkem Technology has developed an EAF process that utilizes SPL and waste material from the steel industry as raw materials for pig iron production. The slag produced is designed to minimize leaching of environmentally harmful elements, making it suitable as landfill. A third example case is a project called “Eyde 0 waste” where industrial Mn- sludges and Fe II- sludges, graded as hazardous wastes, are treated through different reduction techniques for low cost extraction of valuable elements from the sludge, with the aim to make a material suited as a raw material for the steel and/or the manganese industry and to minimize waste.

Elkem is also part of a cluster organization called Eyde. The member businesses which are owned by some of the world’s largest corporations produce specialized products for the global market. The companies export about 90% of their production. The combined annual turnover is around 1.5 billion USD, yearly spending on R&D is above 40 million USD and during the last 10 years they have invested around 1.4 billion USD. Total numbers of employees for the nine members are about 2500.

The Eyde companies work together in developing research and developing projects and have through a process starting November 2012 using key personnel identified a project portfolio of common development projects focusing on resource efficiency and sustainability. These projects are grouped together in the «Eyde Environmental Programme». One important project in the portfolio is the Eyde 0 waste project.

Niobium and its compounds for a reliable value chain - More with less-

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Niobium is from the 54 by EC in 2013 assessed raw materials within the “critical” ones identified at EU level. Niobium is for sure a property determining alloying element and is a necessary (or “critical”) element for enhanced properties of alloys, but is global widely available from ores. 90% of the mined niobium is used for micro-alloying and alloying. The reserves of the actual operating Niobium mines, including the known deposit, largely exceed those of Tungsten. Hardmetals are a synonym for wear resistance and so far dominated by tungsten carbide (WC), which is for WC an application area consuming more than 50% of the tungsten. Recently, niobium carbide spurs to be an alternative to tungsten carbide for wear protection.

The situation in the supply chain, the historical governance indicators and the explored global availability including the long-term geological availability (mined deposits and explored reserves) don´t justify the inclusion of niobium in the list of critical raw materials.

Electronic waste as a source of indium: Drivers and constraints

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During the last three decades, technological innovations, ICT technologies and market expansion into developing countries have significantly increased the production and use of electrical and electronic equipment (EEE). Fast technical progress and the multi-functionality of EEE have also led to an increased number of substances used in EEE devices. A number of materials, formerly no more than scientific curiosities, have nowadays an important role in current and new generations of EEE. This has raised concern about their sufficiency and vulnerability of supply. Therefore, various criticality studies and surveys have been recently conducted worldwide and some raw materials are labelled as 'critical'. However, geological scarcity is not the key issue for determining criticality; more relevant are changes in the geopolitical and economic framework that impact supply and demand, such as growing demand for these critical raw materials in developing economies and for emerging technologies. As a case study of critical materials, this presentation will concentrate on indium and its recovery potential from WEEE.

In 2010, approximately 574 tonnes of indium was produced from primary sources (Talens Peiró et al., 2013). Most of the world's primary indium supply originates as a by-product of processing zinc ores mined in China, Peru, and Australia. Another source of primary indium supply is mines of other types of metals, mostly copper, lead, tin, and precious metals. (Bleiwas, 2010) Key factor in the criticality of indium is competing needs and uses. More than 50% of globally refined indium is used to produce indium-tin-oxide (ITO) for thin films for liquid crystal displays (LCD) (Bleiwas, 2010). Globally, growth in demand for LCD is the strongest in developing economies, for TVs, tablets and smartphones. There is also a growing demand for indium in manufacturing photovoltaic (PV) systems (Bleiwas, 2010). Two types of PV technologies are commonly available; crystalline silicon -based and thin film cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS) technologies (Elshkaki and Graedel, 2013). Thin film (TF) technologies are gaining in importance due to low production costs and the low energy and materials demands. Further, light emitting diodes (LEDs) rely on indium as well. LEDs are superior in energy efficiency, as they convert 100% of the input electric energy into visible light.

Recycling is regarded as a solution to substitute primary resources and decrease environmental loading and, therefore, waste electrical and electronic equipment (WEEE) is potential future source of critical materials, such as indium. However, recycling rates of critical materials are currently very low; for indium, it is under 1% (UNEP, 2011) because of some limitations. One of the main limitations is high dissipation rates; it is estimated that the dissipation rate for indium is up to 90% (Zimmerman and Gößling-Reisemann, 2013). The principal drivers for the dissipation are explicitly dissipative applications, minor concentrations in final products and ineffective collection and recycling systems. Dissipative losses may occur at every stage of the material's life cycle; however, the end-of life (EOL) stage is a noteworthy contributor.

This presentation will discuss electronic waste as a source of secondary indium. First, the drivers of indium recycling from WEEE will be considered and the most potential secondary sources will be identified. Then, the presentation will express main challenges of indium recovery and highlight constraints of the current WEEE recovery system. It is expected that WEEE could be a future source of critical metals; however, it requires more considerations on materials' recyclability in the product design phase, more efficient collection of WEEE and recycling strategies aimed at minimizing dissipative losses. The presentation will argue that the reduction of dissipation of critical materials, such as indium, should have a much higher priority in WEEE recovery.

The significance of the proposed presentation is that it highlights the need to challenge the view that metals in the anthroposphere are intrinsically recoverable. It is put forward that more attention should be paid to sustainable management of critical materials, especially improved practices at the waste management stage. This calls for not only more efficient recycling strategies of WEEE, but also revising priorities in recycling strategies.

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Recycling and recovery of valuable raw materials

Sourcing waste and low grade resources for Phosphorous

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Currently known high grade easily-acquirable phosphate rock reserves required by the fertilizer industry may be depleted within a few decades. Although there will undoubtedly be more phosphate discoveries after current identified reserves are depleted, they will require progressively more effort and expense to extract and refine.

Currently, the EU imports virtually all its phosphorus with the import dependency rate of approximately 92% and, as reserves diminish, this will be the case for other countries that have large unsustainable phosphorus demands.

Current world phosphate rock reserves, concentrated in a few countries mainly China and Northern Africa, will decline forcing the- more costly - extraction of lower grade sources which are burdened by levels of heavy metal and radioactivity contamination. Geopolitical tensions and a globally increased demand of P have already resulted in highly fluctuating and simultaneously increasing trend in the phosphorous price development As the need for phosphorous will increase globally, due to increasing food and energy crop production, these tensions are not likely to disappear. The need to develop phosphorous recovery also from unconventional sources is unavoidable.

Currently only phosphate rock containing relatively high amounts of phosphorous has been utilized effectively. Waste amounts of lower grade rock is considered as overburden and not utilised.

Phosphate extraction from sub-economic reserves and other under-utilized sources will mitigate the pressure of global and regional phosphorus shortages. Further, utilising this phosphorus-containing mine waste will contribute to diminishing the environmental footprint of mining.

In addition to subeconomic rock phosphate reserves, waste rock from iron ore mining and steelmaking by-products enriched in phosphorus are largely unexploited potential sources of phosphorus.

Steelmaking slag and blast furnace slag are by-products of steel and iron production process. Global blast furnace slag generation in 2002 was close to 190 million t and in Europe ca. 40 million t in 2004. Another fairly unexploited source are ashes from biomass incineration, the P-content of which varies between 1 % (wood pellet ash and straw) and ~ 20 % (municipal sludge), depending on the fuel.

We foresee during the next your targeted development and deployment of new technologies that can efficiently utilise these secondary materials For instance Microbiological processes are potentially a cost efficient option to traditional chemical processes for material containing lower concentrations of phosphorus.

When phosphorus is recovered from waste materials and side streams, their phosphorus content and subsequently the risk of unwanted leakage of phosphorus from wastes is diminished. In addition to the phosphorus, the accompanying metals could be recovered for better utilization of natural resources.

This will ease the foreseen future situation where the physical limitations of the resource will become increasingly important.

Beneficiation of metals in assembled printed circuit board by means of flotation

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Currently, waste electrical and electronic equipment (WEEE) is the most rapidly increasing waste type in Europe. High levels of valuable and precious metals are concentrated in the printed circuit assemblies (PCA) which can be found in almost every electronic device. However, harmful impurities and elements are also present in PCAs, which may cause problems in the further recovery processes. Therefore, further mechanical processing of PCAs would improve the quality of the feed for metal recovery by removing harmful substances and increasing the metal concentrations. The objectives of this study were to further mechanically process the PCAs from mobile phones to produce a better quality metal concentrate for further recovery process.

For the study 25 kg of mobile phones including both large and small ones from mid-1990s to recent years were collected. The study was carried out by using full factorial flotation experiments where the variable parameters were agitation speed, aeration rate and pulp density. Prior to flotation a two-step size reduction process were designed and conducted to hand dismantled PCAs from mobile phones. In addition, characterization studies including chemical elements analysis and particle size analysis were carried out.

The results from characterization studies showed that high concentrations of metals such as copper, gold, silver and neodymium can be found in mobile phone PCAs. However, elements such as chlorine and bromine which may cause challenges in further recovery processes are also present in significant levels.

The flotation experiments showed that both Cu and Au enriched to the metal rich fraction. The Cu the content could be increased from approximately 25 % up to 45 % at best with a recovery of 85%. The enrichment ratio for Au was roughly 1.3 at best. Elements such as Cl, Sb and Si that are used in the plastic composite matrix enriched to the froth fraction due to the natural hydrophobic response of plastic particles. Therefore, no chemical additions were requisite in the flotation experiments. The concentration rate of the flotation was at best approximately 2.1. Finally, the full factorial experiment design indicated that agitation effected more strongly on the flotation efficiency than solid content and aeration rate. Best results were obtained with an agitation of 1200 rpm, aeration rate of 3 l/min and solid content of 16%. As the result of experimental work, the produced metal concentrate with low concentrations of disturbing compounds enables its use as a high-quality feed to the primary copper smelter.

Characterization of the bacterial and sulphate reducing community of closed Kotalahti Mine alkaline mine water

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Acid Mine Drainage (AMD) is caused by chemical, biological and electrochemical interactions with metal-sulfide rich rocks of mining sites and quarries. Microbial communities may have a great impact on the environmental stress caused by AMD and have been used as tools for bioremediation of polluted mining sites. Here we characterized the bacterial and sulphate reducing microbial community of two shafts of Kotalahti Mine (Finland), which was flooded after closure. 15 years prior to our study the mine was treated with pigs' manure sludge, which induced sulphate reduction and metal precipitation. Water was collected from two different shafts from depths -10 m, -30 m, -70 m and – 100m. The two shafts different from each other both biologically and chemically. While Vehkankuilu shaft had a pH close to neutral, high concentration of nickel and sulphate, Ollinkuilu shaft water was highly alkaline with low concentrations of nickel and sulphate throughout the 100 m water columns. The bacteria of Vehkankuilu shaft consisted mostly of methylotrophic γ- and β-proteobacteria. Ollinkuilu shaft's bacteria belonged to hydrogenotrophic and methylotrophic β-proteobacteria in addition to a high variety of fermenting bacterial clades. The concentration of sulphate reducers (SRB) was low, at most 4.0×10^3 *dsr*B genes ml^{-1} at -70 m in Ollinkuilu shaft. In Vehkankuilu shaft the highest number of *dsr*B genes was detected at -10 m (1.5×10^3 *dsr*B genes ml^{-1}), with very low abundances below this depth. The SRB detected by *dsr*B targeted DGGE belonged to *Desulfobulbus* in Vehkankuilu water and mostly to *Thermoanaerobacteriales* in Ollinkuilu water. Despite the obvious success of using the mine as *in situ* bioreactor for increasing water pH and removing sulphate and heavy metals by induced sulphate reduction, only a very small portion of the bacterial population in the mine water belonged to sulphate reducing clades.

Treatment of solid waste from the mining industry

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During concentration of various different ores, tailings are produced in massive quantities. Due to two reasons the treatment of tailings is a desirable goal: (1) tailings represent an environmental risk and necessitate mining companies to target resources into waste management and (2) resources are often lost when valuable metals end up in the waste stream. Environmental legislation can be expected to further tighten in the future meaning that technically and economically feasible routes to treat tailings, instead of storing them, can provide competitive advantage to mining companies and even generate new business in the cleantech sector. On the softer side, sustainable waste management could enable the mining company to claim their social license with less effort than currently and have a positive effect on the public image of the company.

In Finland, the annual production of tailings exceeds the annual production of concentrate by 4-5 times. In general the number is not high but still constitutes as an environmental issue. The characteristics of tailings or the routes by which they are produced are numerous as both of these are dependent on the actual ore characteristics, which, in turn, are geographically different. Certain characteristics and consequent challenges can, however, be identified. The beneficiation of sulphidic deposits always presents problems as the tailings generated during concentration have high sulphur content and can result in acid mine drainage and consequent release of metals. In addition, cyanidation during gold recovery presents a major environmental issue as tailings can contain residues of cyanide. The reactivity of tailings is often in the heart of the environmental issues and thus management, commonly containment, of tailings is crucial. The low concentration of valuables is also an issue if treatment of the tailings to obtain value added products is to be executed.

Paste and thickening technologies have developed rapidly over the past few years and their availability has to a certain extent decreased the risk related to tailings storage. A trend arising from improved dewatering has been the use of tailings as mine fill. Although such technology can be beneficial through the immobilization of the metals in the tailings, it does not make use of the valuables in the raw material.

Tailings can, however, contain valuable metals either those recovered in the primary concentration process or others not considered during upgrading. Hydrometallurgical routes to recover metals from tailings have been considered in several studies over the past few years but to facilitate these routes, the waste must undergo pretreatment to decrease the volumetric flow and to improve the water recovery of the primary process. The solid/liquid separation has, however, presented some problems and numerous techniques, such as hydrocyclones and different types of filters, have been suggested for the dewatering of tailings.

The *Treatment and utilization of solid waste from the mining industry (TREWA)* is a research project funded by Tekes under the Green Mining programme. The treatment concept is based on a few significant operations: (1) upgrading through physical fractionation, (2) selective leaching of metals, (3) recovery of the metals and (4) recycling of the solvent. For this purpose, solid/liquid separation, leaching, membrane separation and ion exchange amongst other are being considered.

The particle size distribution of the tailings, obtained from a multimetal (Cu, Ni, PGM) mine operating in Finland, is fairly broad with particle size ranging from a few microns to a hundred micron. The fraction of fine particles is quite significant but it is, to a large extent, the broadness of the particle size distribution that makes for example filtration challenging. Characterization of the tailings has indicated that the nickel is concentrated in the larger particles whereas the copper is concentrated in the finer particles making fractionation possibly even more important. The main mineral phases for nickel and copper are pentlandite and chalcopyrite, respectively. The quantity of gangue minerals, of which majority is pyrrhotite, ranges from 80 to 98 wt-%. The particle shape varies significantly from elongated particles to more sphere-like and cubic ones.

Preliminary leaching experiments have shown that it is possible to dissolve significant quantities of the nickel (recovering up to 90 %) and copper (recovering up to 66 %) in sulphuric acid at atmospheric pressure using an oxidizer. Ambient temperature might not be feasible but, nevertheless, the project aims at developing a process where operational costs would not be increased due to increased pressure or temperature. The leaching experiments have so far been performed on non-fractionated tailings as the fractionation experiments have been conducted simultaneously with the leaching experiments and data on those has not been available. The solid/liquid separation of the undissolved tailings has also been considered in the project and it has been observed that the leaching conditions as well as possible fractionation of the tailings have a significant impact on the success of the separation step.

Thiosulphate leaching system for gold production from primary and secondary sources

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In production of metals from secondary sources precious metals have a significant role from economic point of view, precious metals contribute significantly for example to the value of waste electric-electronic equipment (WEEE). WEEE is the fastest growing waste stream in municipal wastes with an annual growths rate of about 3 – 5 %. WEEE with high content of base and precious metals are regarded as a potential secondary resource and also a new environmental challenge. For the recovery of metals from WEEE, various treatment options based on conventional physical, hydrometallurgical and pyrometallurgical processes are available. Compared with pyrometallurgical processes, hydrometallurgical processes offer relatively low capital cost, reduced environmental impact (e.g. no hazardous gases/dusts) and high metal recoveries with their suitability for small scale applications. These attributes make hydrometallurgical processes potential alternatives for production metals from primary and secondary sources. Hydrometallurgical processes should focus on the extraction of precious metals, since their extraction is of prime importance for economics of a recycling operation.

Leaching stage is often one of the initial operations in the process, and as a result the efficiency of leaching has a primary effect on the technical and economic success of a hydrometallurgical business. The most common leaching agents tested for recovery of precious metals include cyanide, halide, thiourea and thiosulphate. In recent years thiosulphate has been considered seriously as a potential substitute for cyanide for production of gold, because it generally causes fewer environmental impacts. When the thiosulphate process is compared with conventional cyanidation, the thiosulphate process often has the advantages of greater efficiency and versatility coupled with a significantly lower environmental impact. Thiosulphate liquors are also less prone to contamination by unwanted metal ions, hence can be applied to a wide array of raw materials from primary and secondary sources and liquors have a great potential for recycling. Thiosulphate process could offer also many advantages when considering integration of metals recycling process to the metal refinery producing metals from primary sources, because thiosulphate can be produced from SO_2 and S^0, which are by-product of some metal refineries (e.g. zinc refinery). However, widespread commercialization of thiosulphate processes has not yet been achieved. The major problems facing thiosulphate processes are the high consumption of thiosulphate and the challenges posed by the recovery of the gold after the leaching stage. One of the challenges to evaluation and adoption of the thiosulphate process is the complicated chemistry of the leaching system, resulting

from the simultaneous presence of complexing ligands (ammonia and thiosulphate), the stability of thiosulphate in the solution, and the Cu(II)-Cu(I) redox couple. Recent studies have shown that comparable leaching rates can be achieved for gold with thiosulphate as leaching agent for raw material from both primary and secondary sources. This work reviews the current understanding of thiosulphate chemistry and mechanisms of gold dissolution, and discusses the ways to manage the leaching system. It then reviews results of various gold leaching studies that have been reported in the literature. Development history of gold production with thiosulphate system is discussed and gold recovery options as well as environmental issues are also considered.

Chemical-mineralogical sorting of mineral construction and demolition wastes for a better recovery

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Mineral construction and demolition wastes (C&DW) account for approximately 25% - 30% of the entire waste stream within the European Union [1]. One means of bringing recycled construction materials back into the materials cycle is to reuse them as feedstock in production. To establish a closed-loop cycle in the masonry industry it is necessary to ensure a sufficient purity of crushed and sorted recycled material.

In CDW recycling, the preference to date has been to apply simple but proven techniques in order to process large quantities of construction rubble in a short time. This is in contrast to the increasingly complex composite materials and structures in the mineral building materials industry (Figure 1).

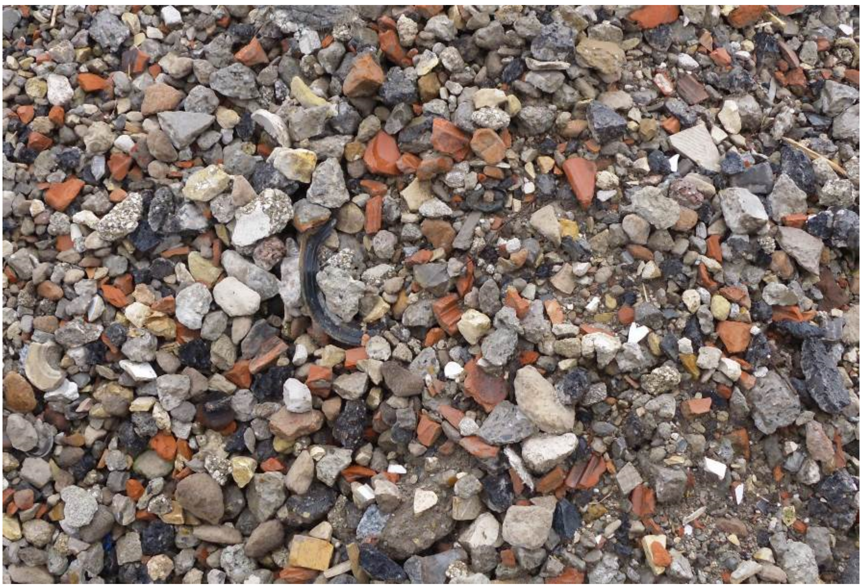

Figure 1: Material diversity (fraction 0/45 mm).

The challenges of processing composite material waste streams from modern structures have been already discussed in [2]. The main process is characterized by manual sorting followed by a crushing step. This sequence will presumably no longer be suitable for the production of homogeneous recycled materials from the more and more complex composite materials. In order to physically unlock usable material, it is necessary to liberate particles through comminution to a grain size smaller than is hand sortable (≤ 45 mm). Subsequently, a sorting step is required to turn the recycled mixture into homogeneous material fractions.

To increase the recovery ratio in shorter term, conventional crushers can be used to liberate valuable aggregates by liberation comminution. Thus, both steps in the main process must be reversed. Through such a modification, the previously unsortable fraction (mostly 0/45 mm) as well as diverse composites could be processed at a high quality level. [2]

Whereas conventional crushers can be used for liberation comminution, appropriate sorting technologies must be still developed, to, finally, turn mineral mixtures into usable materials. Sorting of minerals can be achieved according to either its physical or chemical-mineralogical characteristics. Due to the large material diversity and the arrival of new building materials - e.g. due to energy saving regulations for buildings - with a wide range of densities, sorting by physical properties, such as the bulk density, may be difficult in future.

Therefore, sorting processes focusing on chemical-mineralogical characteristics gain more and more importance.

One of the most promising techniques is sensor-based sorting technology. Through the installation of such sensor-based single particle sorting devices in building materials recycling, the heterogeneous bulk materials could be converted into homogeneous material fractions. The performance limitations of the prevalent sensor techniques, as well as economic aspects, must be considered. At the present level of technology, only coarser aggregates can be technically and economically sorted by this technique.

Other possibilities for sorting, especially of recycled sands, are described in [3] and [4], among others.

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Minerals and Geomicrobiology Research for Recovery at VTT

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Minerals and geomicrobiology research at VTT is developing (bio)-hydrometallurgical methods for recovery of minor species including rare earths from waste streams and raw materials. The methodologies used include development of bioleaching processes of primary and secondary materials including mine tailings, landfill materials, industrial slags, incinerator ashes and electronics waste.

Bioreduction is applied for example using sulphate reducing bacteria to reduce sulphate into hydrogen sulphide and further to poorly soluble metal-sulphide precipitates which is important for waste water treatment in mines.

Biosorption using fungal matter has been applied to recover gold from leachates of PCB boards and heavy metals from mine waters. The bioprocessing work involves deeper understanding of the microbial life. VTTs microbial library has been active for over 50 years now.

Both bioleaching and bioreduction are planned for pilot scale operations. VTT is developing hydrometallurgical platform and competences that consist of hydrometallurgical processing technologies including leaching, precipitation, solvent extraction, ion exchange, and bioprocessing. The experimental work is supported by in-house thermodynamic modelling, microbial analyses, and flowsheet techniques.

Recovery of metals from spent car NiMH batteries by hydrometallurgical methods

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The increasing use of hybrid cars leads to the higher consumption of rare earths elements (REE) for the car battery production, when nickel metal hydride (NiMH) batteries are used. NiMH batteries contain approximately 3kg of REE, 11kg of Ni and 1.5kg of Co, thus spent NiMH can be considered as secondary raw material of REE and other valuable metals such like Ni and Co.

Hydrometallurgical technologies for recycling of spent NiMH batteries have been developed applying acid leaching and solvent extraction processes. Process has been developed for NiMH batteries, which can be dismantled manually or mechanically. Depending on the way of dismantling, three different materials can be obtained (cathode plates, anode plates or mixed material). Cathodes consist of nickel metal mesh and active material, which contains metals such as: Ni, Co, Zn and Y. The anodes consist of steel plate and active material containing: Ni, Mn, Co, Al, La, Ce, Nd and Pr.

The proposed technologies have been designed to recover metals either from cathodic and anodic material or from mixed (cathodic and anodic) material. Hydrochloric acid (8M) is used as a leaching medium and leaching temperature is 30°C. The extraction system consists of the solvating extractant trialkylphospine oxide mixture Cyanex 923 and tributyl phosphate diluted (TBP) in kerosene. Pre-main extraction process (8% Cyanex 923, 10% TBP, 82% kerosene) is used to remove Fe and Zn from cathode and mixed material leachates. Zn and Fe are extracted in 4 extraction stages followed by 3 scrubbing stages to remove co-extracted metals and 4 stripping stages to remove extracted Fe and Zn (~99%). Rare earth elements are separated from Ni, K, Mg in 4 main extraction stages (70% Cyanex 923, 10% TBP, 10% kerosene, 10% 1-Decanol). High purity of nickel (> 99.9%) in a raffinate can be obtained after main extraction. Loaded organic is stripped with $NaNO_3$ and HNO_3 to remove Mn and Co (95%). Ce, La, Nd, Pr and Y are recovered by using 1M HCl from the organic after previous stripping with 1M $NaNO_3$. Proposed technologies have been tested in a counter-current system using pilot plant scale mixer-settlers. The testing of all processes (pre-main extraction, main extraction, scrubbing and stripping) in proposed loops provides necessary data to optimize the technologies and then make them suitable for scaling up in a real plant.

KEYWORDS: spent nickel metal hydride batteries, rare earth elements, recycling, leaching, solvent extraction.

VTT's mineral economy programme (MINECON) and Flexmet hydrometallurgy platform for recovery of critical metals

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Metal concentrations in primary deposits are lower than before and secondary sources, such as EOL products, mineral residue streams and urban landfills, offer competitive concentrations within a number of technology and base metals. These trends lead to a need to develop new technologies for profitable extraction from low grade sources, as well as proper management of the socio-environmental impacts related to mineral extraction. In addition to more efficient extraction, the looming resource gap requires more careful use of mineral raw materials in a wide range of products. Substitution of critical metals plays therefore an important role in reducing material dependencies but it should not lead to decreased product performance or increased environmental impacts. There is thus a clear need for tools and methods that allow for more rigorous and sustainable material design. The mineral roadmap created by VTT, Aalto University, Geological Survey of Finland, Ministry of employment and economy, Technology Agency of Finland and Outotec in 2012 revealed a demand in energy and material efficient solutions for mining, processing and product design, as well as for sustainable water and waste management solutions throughout the value chain. Against this backdrop, the VTT Mineral Economy innovation programme (MINECON) is designed to produce solutions that cover the mineral value chain in carefully chosen strategic segments with high leverage for scientific excellence, IPR and foster new sustainable businesses. As a part of improving research infrastructure in recovery of critical and economically important metals a Flexmet hydrometallurgical pilot facility has been under construction.

MINECON Vision: VTT will promote a major leap in the mineral sector transformation from a reactive throughput industry towards a system based on: design driven innovation, resource wisdom and closed loop thinking, and knowledge management

MINECON Mission: to understand the properties, sustainable processing, recovery, structure and performance of mineral raw materials throughout the value chain so as to optimize the environmental and economic impacts of products and processes.

MINECON Strategy: to conduct research on material behaviour in industrial and consumer applications during production, use and recycling and to deliver technological solutions for the critical stages in the mineral value chain.

MINECON co-operation: MINECON programme will have two main short term deliverables: designing and implementing a high impact role for VTT and Finnish stakeholders in the Knowledge and Innovation Community (KIC) in raw materials. KIC development requires new carrier projects from Horizon 2020 (SPIRE, SC5, Finnish Academy, and TEKES Green Mining program). In addition, MINECON will prepare, through the KIC nodes, raw material commitments and Horizon 2020 programmes for the European Innovation Platform (EIP) on raw materials. The main function of the raw material KIC is to enable new products and companies to enter the market.

Recovery of Rare Earth and By-product Metals from Streams

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Critical metals have gained great amount of attention and new processes and technologies have been investigated recently. The fact is that critical metal are often by-product metals and driver for excavation and recycling is elsewhere. For example tellurium recovery is related to copper mining and indium, gallium and germanium appear in the zinc deposits. Rare earth metals are often by-products in mining for example in apatite sources. Hydrometallurgical processing and recovery of REEs, In, Ga, and Ge are looked as an example. Leaching and recovery using solvent extraction from leachate are discussed and extraction processes are summarized. Further process assessment and technology development for recovery and recycling as well as new Flexmet hydrometallurgical platform development is discussed.

Critical Metals Recovery and Recycling - Hydrometallurgy

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VTT is developing hydrometallurgical methods for recovery of minor species including rare earths from waste streams and raw materials. Recycling methods and possibilities of critical metals from end of user products are looked in EU collaboration program AERTO and in several joint industrial projects. Different process routes and recovery methods for minor species from ores, tailings, residues, WEEE, and PCBs of mobile phones are studied.

VTT is also actively participating in European Union programs like ERA MIN, CRM INNONET, EIP RM, ERECON, and EIT KIC. These programs highlight the importance of raw materials issues within EU and targets to increase resource efficiencies and recycling rates in a cost effective manner.

The global demand for metal raw materials has grown exponentially. For example during fifty year the production of copper has increased four times and steel six times. The demand of rare earth elements has increased in the same phase. There is a great need for a sustainable mining of REEs as well as developing more efficient collecting, pre-treatment, separation, processing, and recycling of minor species from various waste streams and primary sources.

New technologies aid leading towards sustainable use of earth's resources through increased efficiency and improved material utilization, re-use, and recycling.

It is clear that new ore has to be mined to meet the increased demand of rare earths and other critical metals. Simultaneously recovery rates from waste streams have to be improved when technically or economically possible.

VTT is developing hydrometallurgical platform and competences that consist of leaching, precipitation, solvent extraction, ion exchange, and bioprocessing units. The experimental work is supported by in-house thermodynamic modelling and flowsheet techniques.

Feasibility study for Cr recovery from stainless steel slag

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Turning waste into a resource is one of the key elements defined in the Europe 2020 Strategy and its flagship initiative on "A Resource Efficient Europe". Various types of industrial waste and by-products produced by the ferrous and non-ferrous industry (such as metal slags, ashes and sludges) may still contain valuable materials such as technology metals which can be used as raw materials again. Yearly several million tons of these waste types are generated in Europe. Currently most of these wastes are still disposed of in landfills or used as low grade materials in construction applications. Due to changing economic conditions and technological innovations, these types of waste have become potential resources for the recycling and recovery of various valuable metals and critical raw materials. At the same time, through metal removal the mineral matrix material is cleaned from these contaminants and can be used as a valuable product in the building industry without posing a risk to the environment.

This work focusses on the treatment of historic stainless steel slags containing about 1 wt% of chromium (Cr). Chromium has recently been defined as a critical raw material by the EU and is a key raw material for the production of stainless steel. Furthermore, Cr can pose environmental and health issues when leached over time from the landfilled slags. The aim of the presented work is to selectively remove Cr in order to (i) safely re-use the matrix material and (ii) to recover Cr from this low grade (secondary) ore.

Since the traditional recovery of Cr (roasting with Na_2CO_3 above 1100 °C) is energy consuming and not applicable to low grade ore materials, research for a safe and economically feasible Cr-recovery process is required. Therefore, as a feasibility test, several hydrometallurgical treatments were investigated such as acid and alkaline leaching with ultrasound or mechanical activation as well as pressure leaching.

A thorough analysis of the slag shows that Cr is present both in micrometer size stainless steel droplets, entrapped within the mineral slag material, and as chromates in a mixed oxide spinel phase. Therefore, a comminution step is required to gain access to the entrapped Cr and simultaneously enhance Cr leaching by mechanical activation. Furthermore, sonication is applied as a physical treatment step to enhance Cr leaching. These treatments are assisted by amorphization and cavitation effects, respectively. Here, the slag was milled to <125 µm. Subsequently, a range of hydrometallurgical extraction methods was screened to optimally extract Cr from the studied slag material. Citric acid leaching in the presence of an oxidant

(H_2O_2) did not prove successful since the alkaline slag material easily dissolves, causing a low selectivity towards Cr leaching. Also, acid leaching with addition of extra reaction energy, in the form of ultrasound, did have a negative effect on the selectivity of Cr leaching, and only increased matrix material (Si, Mg, Ca) dissolution. On the other hand, oxidizing alkaline leaching shows promising results towards a selective Cr recovery from the slag material. Alkaline leaching methods are studied and compared, including alkaline pressure leaching at elevated temperatures (220-260 °C), initial oxygen pressure at room temperature (pO_2, 8-10 bar) and different alkaline sources (NaOH and Na_2CO_3). Alkaline pressure leaching was selective for Cr leaching leaving most of the matrix material in the residue. Furthermore, Cr leaching by alkaline pressure leaching doubled after adding an initial mechanical activation step.

Similarly, reaction parameters for ultrasound assisted alkaline leaching at room temperature are investigated and compared.

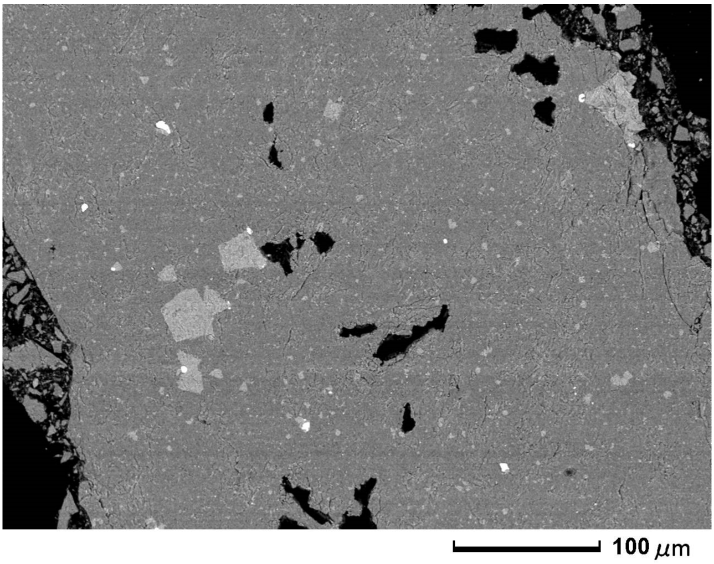

Figure 1: Stainless steel slag grain consisting of Ca(Mg) silicate. Small Mg-Cr-Ti-Al oxide crystals (light gray) in the silicate matrix, as well as some very small metal droplets (white) both contain Cr.

This thorough study of the hydrometallurgical recovery of Cr from historic stainless steel slags provides new insights which will enable the future recovery of valuable and critical metals from complex low grade ores, both primary and secondary.

Recovery of rare earth elements from end-of-life fluorescent lamps

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With the rapid advancement of technology, the demand for rare earth elements has increased considerably. Many countries are facing problems securing sustainable supplies, a fact acknowledged in many publications. Due to the ever-growing demand and supply problems, rare earth elements are now considered to be of critical importance. This has focused attention towards their recovery from end-of-life products and industrial waste streams, with fluorescent lamps being one of the targets.

The research presented here is aimed at developing a hydrometallurgical process for the treatment of fluorescent lamp waste, with the goal of recovering the rare earth elements that these lamps contain. In comparison to other efforts in this field, the investigations were carried out using real waste samples originating from a discarded lamp processing facility. The complexity of the material (a contaminated mix of glass, metallic and plastic parts, phosphors, remaining electronics and other impurities) makes already proposed methods a challenge and makes additional research necessary.

Cerium, europium, gadolinium, lanthanum, terbium, and yttrium were the rare earth elements identified in the material, alongside many other impurities (calcium, aluminium, barium, magnesium, manganese, boron, copper, zinc etc. compounds). The rare earth elements can be leached in two groups in a two stages. Yttrium and europium can be effectively leached at room temperature using dilute mineral acid solutions (more than 95% leaching efficiency). Leaching of the other rare earth elements requires increased acid concentration and increased temperature. Ultrasound assisted digestion was also shown to improve the leaching efficiency. Recovery of rare earth elements from nitric acid media was studied using solvent extraction. Commercial extractants such as tributyl phosphate and Cyanex 923 (trialkylphosphine oxides) have been used, together with various diluents such as kerosene, TetraPropyleneHydrogenated, tertbutyl benzene and 1-octanol. For both extractants, the distribution ratios were noticed to decrease in regard to the diluent used as follows: TetraPropyleneHydrogenated, kerosene, tertbutyl benzene, 1-octanol. Cyanex 923 led to higher distribution ratios in all systems, making it the extractant chosen for further studies. Separation of heavier elements (terbium, yttrium, europium and gadolinium) from lighter ones (cerium and lanthanum) is possible due to larger separation factors. Selective stripping of REEs from the co-

extracted elements (iron and mercury) in the Cyanex 923/kerosene system was easily achieved using concentrated hydrochloric acid. Further recovery of the extracted iron and mercury is possible using either oxalic acid or nitric acid solutions. Extraction of REEs as a group was successfully achieved at laboratory pilot-scale, in a counter-current mixer-settler system.

KEYWORDS: florescent lamp waste, rare earth elements, recycling, waste treatment, leaching, solvent extraction.

Management and policy in the mineral economy

Sustainability in mining industry - how to measure it?

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Modernisation of process industry requires achieving sustainability in all operations covering the whole value chain from raw materials to end-of-life phase. At present, process and mining industry is lacking sustainability control tool in local plant and mine level. Existing indices and rating systems, such as Dow Jones Sustainability Index, evaluate mostly corporate level sustainability and assess mainly strategic and management level, not operational or plant level. In addition, existing global sustainability benchmarking indices and tools fail to address small and medium size enterprises or plant and mine level sustainability and resource-efficiency issues such as process industry -specific key aspects of sustainable resource use. Therefore, a novel sustainability control tool is needed to promote sustainability and especially resource-efficiency throughout the value chain of process and mining industry.

One of the European Union's (EU) fundamental objectives is sustainable development (COM (2003) 302 final). Additionally, the final document of the UNCED conference (Agenda 21) encourages individual countries and organizations to develop sustainability indicators for the basis of decision-making and to promote their global use (UNCED, 1992; Agenda 21, Chapter 40). Also Dahl (2012) suggested that better indicators of progress towards sustainability are needed taking into account that suitable indicators should indicate change in dynamic systems covering e.g. resource limits and economic instability.

The control tool for process industry, developed in research project[1], will provide, after development work, the means for mining industry to meet sustainability standards. The developed tool will be applied to continuous monitoring of progress towards improved resource efficiency and sustainability performance including benchmarking with other processes. Sustainability impact assessment will encompass the application of specific indicators to evaluate environmental, economic and social impacts of the mine. The environmental index will provide information that can be used to guide investment decision-making towards most efficient, environmentally friendly and sustainable options in mining processes. The economic index will show the price of sustainability improvements and costs associated with various options. The social index will demonstrate the level of social sustainability covering the whole value chain. The economic and social sustainability elements of the designed tool will link industrial operations to the local society and

[1] Research project Metrics of environmental efficiency for metal production technologies (METRIC), 2009 – 2014, funded by the Finnish Metals and Engineering Competence Cluster Fimecc Ltd (http://www.fimecc.com/en/index.php/Main_Page).

economy and will therefore contribute to better identification of associated actual impacts and costs.

There is a demand for a mine level sustainability performance measurement tool to support both strategic and operational management, as well as internal and external communication covering, for example, customers, local communities, authorities, shareholders, investors and media.

Governing international mineral flows: challenges created by knowledge and human needs

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Since the 1970´s the interest towards the environmental effects caused by human actions and the capacity of the Earth to sustain growing human population and increasing wealth has been growing. This has lead to the invention of the methodology to study production chains, for example, life cycle assessment and material flow analysis methodologies. The core idea of these methods is to provide knowledge that companies, governments, organizations and consumers can use in making decisions that support less-material intensive and environmentally harmful production technologies. In contrary to the general idea of less-consuming humanity, the demand for mineral-based raw materials has increased rapidly from the beginning of 21st century due the increasing well-being in Asia but also due the demand for "new" high-tech minerals to support mainstreaming of complex technological innovations. This development is driven by human needs for infrastructure and basic welfare, energy, communication and luxury. Due to the open mineral-markets and differentiated supply and demand regions, this has led to substantial transcontinental trade flows of mineral commodities.

This picture creates an interesting contradiction which can be discussed by sustainable development principles and applied to a governance of the international trade flows and production chains. Minerals and mining can be argued to be non-sustainable activities as they decrease the amount of resources in ground to be in use for future generations. However, the minerals mined now have raised countless people from poverty in Asia, and earlier in other continents, and will most probably support also the well-being of the children of these people. In this sense, the key question in supporting the sustainable material resources supply for the societies is in keeping the mined resources in use as long as possible via recycling and material efficiency (that is, circular economy) starting from the product design.

As trade flows and production chains are increasingly international, the key question in governing and striving for environmentally, economically and socially best practices is the knowledge for which the decisions can be based. For studying the mineral based production systems the data for the mine sites is generally readily available in Finland through public reporting of companies and authorities, at least for those people speaking Finnish. In the contrary, for studying the international supply chains the data quality and representativeness can be very heterogeneous. The situation has been getting better lately due the industry´s own actions in reporting and the emergence of business branch focused in collecting and sharing global information (e.g., about mine sites, companies, environmental effects) for third parties. However, although the data in these databases can be very detailed for specific locations its usability for other locations can be restricted. This calls for proper sensitivity and uncertainty analyses.

As a conclusion, making good governance is making good decisions based on comprehensive knowledge. The production chains and material cycles are increasingly international. Studying the sustainability of these chains and cycles, and eventually governing the actions of companies, nations, organizations and people in international context, needs improvements in international information system, at least when considering mining.

Towards higher impact of research and innovation on European mineral economy - Accelerating competitiveness and sustainability

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This article considers European green economy in a wider framework of research and innovation (R&I) policy of the European Union. The purpose of the article is to outline a forward looking analysis of the European green economy, related R&I policies, and their linkages to the grand socioeconomic challenges in the areas of resource efficiency, raw materials and climate change. The objective is to assess ex-ante impacts of the European R&I activities on decision-making in order to accelerate the transition towards competitive European eco-innovation in global markets and to support sustainable development worldwide. The article builds on the EU FP7 project RECREATE the starting point of which is that European research in the three focus areas above in Europe is fragmented[2]. Due to fragmentation the support of research to private and public actions in the EU and Member States is fragmented and incoherent. The article outlines an integrated and holistic multi-regime approach for the analysis of a transition shift from the current to more integrated R&I mode, which leads to significant support and impact from R&I to private and public decision-making. The research methodology is based on the multi-level perspective (MLP) framework and multi-regime approach (Raven and Verbong 2007) and foresight methodologies. The paper discusses some conclusions based on preliminary results of RECREATE study and of related former studies on barriers and carriers of horizontal R&I policies. The aim of the RECREATE project, funded by the European Commission, is to examine the future directions in the research fields of Climate Action, Resource Efficiency and Raw Materials within the Horizon 2020 programme.

[2] REsearch network for forward looking activities and assessment of research and innovation prospects in the fields of Climate, Research Efficiency and raw mATErials

The social license to operate: Exploring and testing its assumptions, preconditions and limitations in the case of mining in Finland

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The debate around the social license to operate (SLO) approach has been lively in recent years. Although this approach has mostly been developed in extractive natural resource industries, its use is also increasing in other industrial fields. Actors in the mining industry have invoked SLO in their efforts to respond to problems of social acceptance. In its elementary forms SLO is seen as referring to social acceptance granted by a community to either a mining or mining exploration project. In spite of SLO's popularity as an instrument of the mining industry, it has been relatively little studied theoretically, nor has there been much empirical testing of the approach.

In our study we have focused on the preconditions and limits of SLO, starting from the idea that a narrow definition of SLO requires a more thorough analysis of the societal prerequisites of the approach and also empirical testing of the assumptions and factors related to SLO. We share the view that SLO can develop in local level interaction, but more attention should be paid to its spatial, socio-historical and socio-demographic correlations. These factors are not so easily reduced to community level social interaction as is assumed in the narrow view of SLO. The importance of pre-existing conditioning attitudes underlying SLO will be indicated by analyzing the empirical data (N = 1,064). The SoLiMi ("Preconditions and tools for social license to mine") project conducted a survey in January-February 2012 with a questionnaire targeted at the Finnish administrative areas of Uusimaa, North Karelia, Kainuu and Lapland. Eastern and Northern Finland are areas with increasing mining activities. Uusimaa in our study represents the increasingly urban part of Finland, where mining is virtually non-existent. The SoLiMi research project is a joint enterprise of the University of Jyväskylä and the University of Eastern Finland and part of TEKES' research programme entitled Green Mining.

How National Variations in Governance Affect the Social Licence of Mining

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The mining industry is facing global pressures towards applying the overlapping sets of principles indicated by the terms responsible mining, green mining, or sustainable mining. This paper aims to investigate the history and advances in corporate social responsibility in the mining industry focusing on collective actions and broad, multi-stakeholder efforts to achieve governance of the industry both globally and in three specific counties.

In sustainability and environmental matters, there is a trend towards more voluntary policy and planning instruments (soft-law, e.g. environmental and social impact assessment) and away from the state-led regulations (hard law). In different countries these modes of governance have different features and have progressed at different rates. We introduce the concept of the social licence to operate (SLO) as analytic framework that integrates national variations in institutional contexts with national differences in CSR pressures exerted upon the mining industries in Brazil, Canada, and Finland.

The concept of the SLO originated in the mining industry. It was coined by a Canadian mining executive, Jim Cooney of Placer Dome Inc., to draw industry attention to the power of stakeholders to raise project costs, or to stop projects completely. Nearly 60 percent of the publicly traded mining companies in the world are listed on the Toronto Stock Exchange. They either explore for minerals or exploit proven deposits in countries around the world. Because of this, Canadian companies have faced the full diversity of governance regimes. At home, however, they face disputes and confusion over who does, can, or should control mining company access to mineral resources. We briefly outline Canadian efforts to transform the SLO from a metaphor into a management tool. Progress has been made in developing universally applicable quantitative measures of the SLO and in applying stakeholder network analyses to discern which stakeholders are more influential in the socio-political dynamics that determine the levels of acceptance of mining.

Brazil is emerging from a historical pattern in which mining companies and their connection in the government made all the decisions with very little stakeholder input. Today, democracy is well established and there are pressures for greater transparency in mining decisions and regarding the flow of financial benefits. Moreover, sustainability concerns are taking root and leading to questions about many different kinds of extractive and infrastructure developments.

In Finland, mining has historically been controlled by the national government. Because the state mining company was seen as an agent of government, its 'social licence' overlapped extensively with the social licences of election winners. The state miner did not need much a distinct social licence of its own. There was a relatively high level of public confidence in regulatory effectiveness of the elected government. With more privatization and the arrival more foreign companies, however, the social licence is rising in importance for mining companies operating in Finland.

A comparison of the three countries suggests that two factors affect the need for a mining company to gain a SLO from stakeholders. The first dimension is the stakeholders' level of trust in the legal licensing process. The second is stakeholders' collective belief that they can influence the industry. Where trust is low and perceived ability to influence is high, the need for a SLO from stakeholders is highest. Historically the needs for a SLO in Brazil was low because, even though stakeholders had little trust in the legal licencing and regulatory process, they did not believe they could influence the industry. It was also low in Finland but for the opposite reasons. Stakeholders had a high level of trust in the legal licencing and regulatory process and were confident they could influence it to influence the industry. In Canadian domestic mining operations, stakeholders know they can influence the industry and have only a moderate level of trust in the legal licencing process. Therefore, mining companies need a SLO. In their international operations, Canadian companies also need a SLO because they so often work in jurisdictions where the trust in the legal licencing process is very low but stakeholders' collective belief that they can influence mining companies directly is above average.

Potential industrial symbiosis products title – Review of EU and Finnish policy and legal framework

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The purpose of this abstract is to assess the policy and legal status of both multi-stream residues and potential secondary products and whether there could be environmental benefits associated with the utilization of multi-stream residues from integrated mills as raw materials for potential secondary products in Finland. It would be ecologically preferable, if suitable industrial residues (as examples) could be suitably formulated, processed, and then safely and beneficially returned back to agricultural and forest ecosystems as a fertilizer/ameliorant, or reused as construction agents for example, instead of being disposed of to landfill. Such an approach would both conserve virgin materials, recycle materials back to beneficial uses and in some applications recycle nutrients back to ecosystems. The starting point must be reviewing waste related EU and Finnish policy and legal instruments to identify potential constraints.

Due to the practical obstacles of the residues, the conclusion must be that the starting point must be reviewing waste related EU and Finnish policy and legal instruments to identify these potential constraints. The current and emerging EU and Finnish policy and legal framework is a strong driver for progress towards a sustainable recycling society. Thus, the overall objective of this study is to review the status of potential symbiosis products and multi-stream industrial residues within the EU and Finnish waste-related policy and legal framework. Do the selected EU and Finnish instruments support or create barriers to the development of potential symbiosis products?

Waste legislation and policy in Finland is firmly based on EU waste regulation. Different instruments of the EU's waste policy therefore had a central role in the review. The following instruments were addressed: the Waste Framework Directive (WFD, 2008/98/EC), the Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals (REACH, Regulation (EC) No 2006/1907), Communication from the Commission to the Council and the European Parliament on the Interpretative Communication on waste and by-products (COM/2007/0059) and Council Regulation (EU) No 333/2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC. The review of Finnish waste policy instruments concentrated on the National Waste Plan for 2016 (FE14/2009), the new Waste Act (646/2011), and the Government Bill on the new Waste Act (HE 199/2010). The Waste Tax Act (1126/2010) was also taken into account along with various specific instruments concerning residue-based fertilizers.

The EU Waste Framework Directive (WFD, 2008/98/EC) covers measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste, and by reducing the overall impacts of resource use whilst improving the efficiency of such use. The directive was renewed in 2008 with the aim to, among other issues, encourage sustainable residual use by, e.g., clarifying the waste status of materials. The fundamental element of the WFD is the waste hierarchy (art. 4). In practice, the waste hierarchy steers the different waste prevention, recovery and disposal obligations of the directive which specify the prerequisites for, e.g., using waste as a resource and substituting natural resources by residual materials.

The implementation of the WFD was one of the main objectives of the renewal of the Finnish Waste Act in 2011. In general, the revision process aimed at modernizing Finnish waste legislation in accordance with EU legislation and at making changes to the overall operational environment. The new Act (646/2011) came into force on May 1st 2012, and aimed at steering waste streams into preferred activities in line with the waste hierarchy, clarifying duties of operators, and at enhancing monitoring. In addition, a more clear definition of waste, e.g., further development of producer responsibility as well as follow-up of waste quantities by producers and consideration of material efficiency in the context of environmental permits are among the new focus areas.

One of the main objectives of modern waste policy is the strong promotion of recycling targets and continually increasing incentives for the use of recycled materials. Also in Finland, the sustainable use of natural resources, besides other aims such as well-functioning waste management practices, is one of the cornerstones of waste policy. National approaches to waste management have been described in detail in the National Waste Plan (FE14/2009) approved in 2008, which is a nationwide strategic plan running to 2016. The plan lays down the principles and objectives of waste management and waste prevention and proposes implementation instruments for each goal and objective (FE14/2009). In general, the Plan aims at preventing waste generation and reducing the harmful health and environmental impacts of waste. The creation of enabling conditions for recycling and increased material efficiency is one of the key elements of the plan.

In addition to the potential within specific industrial sectors, cross-industrial residue utilization and novel symbiosis products could have a role in increasing the sustainability and environmental performance of modern process industry. Overall, this is in line with the waste hierarchy, but the realistic possibilities of such reuse may be dependent on whether the residues are regarded as waste or products.

The policy and legal review suggest that waste legislation and policy strongly promote reuse of waste materials and recycling targets, but meeting the demands of a ‘recycling society’ may require further development of the legal definition of waste and product-based legislation and standards.

Investments in Resource Efficiency – An Analytical Assessment Framework and Review of Evidence

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This paper contributes to and reviews the (small, but growing) literature on investments in resource efficiency, and presents two complementary frameworks for assessing and prioritising resource efficiency investments, based on conventional economic theory. This approach is also a criticism of standard commercial investment appraisals, which may not only omit environmental aspects (with potentially negative financial knock-on effects), but also fail to account for crucial barriers to project implementation.

A brief introduction offers empirical evidence on material use and productivity patterns in low and middle-income economies (exemplified by Europe, Central Asia, and Northern Africa). It is evident that despite significant increases in commodity price levels and volatility, resource productivity in these countries is trailing behind several developed economies (even when controlling for heterogeneous economic structures). Thus, catching up with more resource efficient peers has the potential of delivering both economic and environmental benefits at a substantial scale.

Firstly, in order to conceptualise the potential of closing such an efficiency gap, this paper offers a comprehensive review of the economic, environmental and political costs and benefits of resource efficiency investments relative to inaction. The analysis not only accounts for direct, but also indirect effects. It is concluded that – given certain assumptions – the literature on resource efficiency investments tends to suggest positive net benefits, especially when considering non-monetary dimensions. This paper argues that the proposed cost-benefit framework should be applied systematically to the assessment of specific resource efficiency investments in order to understand their direct and indirect consequences.

While such a cost-benefit analysis can potentially identify cost-effective investments, implementation in practice may nevertheless be obstructed by investment barriers, which cause and perpetuate inefficiencies. Therefore, it is critical to understand the structural causes of inefficient resource use, and how they may affect the success of investments.

Thus secondly, a systematic framework for analysing barriers to resource efficiency investments is proposed. Based on the First and Second Fundamental

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Welfare Theorem, the framework assesses how the theoretical assumptions of perfectly competitive efficient markets are violated in practice. A typology of barriers is presented, distinguishing between information constraints, capacity constraints, financial barriers, uncompetitive market structures, and fiscal mismanagement. Each type of barrier is illustrated with practical evidence and the relevance to resource efficiency investments is highlighted. In this context the paper also discusses how uncertainty and systemic risks (e.g. commodity price volatility) may exacerbate existing investment barriers. Such an analysis of investment barriers is argued to be critical for prioritising action, and achieving sustainable improvements of resource efficiency.

The paper concludes by offering the blueprint for a comprehensive policy strategy, which addresses both the *causes* and *symptoms* of resource inefficiency, through both *financial* and *technical* support, at both the *micro* and *macro* level.

Overall, this paper calls for case specific analyses, which go beyond standard commercial investment appraisals, and take into account the costs of inaction, environmental and social externalities, as well as investment barriers. The analytical foundation of this paper emphasises practical applicability, and is based on an assessment framework for resource efficiency investments, developed at the European Bank for Reconstruction and Development.

Key words: Resource efficiency, Investments, Costs and benefits, Barriers, Market interventions

JEL classification: L60, O31, O33, Q38, Q56

Towards greener mining: Comparison of legal frameworks and policy instruments to improve resource efficiency in mine tailings management

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Globally, mining is seen as an important factor for welfare creation as mineral commodities form the cornerstone of modern societies. It is expected that the demand for minerals and metals continues to increase in the future. Scarcity of mineral raw materials together with health and environmental risks related to extraction, processing and reclamation are making enhanced resource recovery and resource efficiency strategies the future focal points of national mineral policies. This study focuses on mine tailings – as by-products of processing they are potential environmental and health hazards due to their chemical composition especially in case of possible run offs and tailings dam accidents. In addition, most tailings still contain valuable minerals and metals. Tailings can cause environmental and health hazards long after closing the mine site. Tailings management practices are thus of utmost importance. Reprocessing of tailings would result in enhanced mineral recovery hence improving both mineral economies' resource efficiency and minimising health and environmental risks by providing more stable and less hazardous residue stockpiles or ponds.

In theory, well defined policy goals and smartly designed regulatory frameworks, which would offer incentives for the mining industry for developing and utilizing cost effective processing technology solutions for tailings management, would enable improved mineral resource recovery. This in turn would have positive impacts such as improved resource efficiency, less environmental and health damaging substances lying on deposits, socially more acceptable mining and more profitable business – win-win situation both the economies and industry. By using regulation theory and comparative legal and policy analysis as research methods, this study aims to analyse different factors contributing to the management of tailings, i.e. choice of regulatory method and business environment, and what kind of regulatory regimes would provide sufficient incentives for companies to develop more efficient, yet cost effective, processing technology leading into enhanced material recovery and possibly additional 'firms-going-beyond-compliance' benefits. Policy instruments' capacity for promoting innovation in the tailings management is set as a premise for the analysis.

In the light of this optimal theoretical framework, current regulatory frameworks related to tailings management in a few selected example countries are analysed. The aim is to find out how tailings are currently regulated in the target countries and to what extent, do resource efficiency and enhanced mineral recovery play a role in their mineral policies. Finland, Norway, Canada and South Africa as target countries enable covering the North-South dimension while also considering the challenges related to the tailings management brought by mining in the Arctic regions. By analysing the situation in countries which differ from their climatic, geographical and cultural (socio-legal-political) features and maybe even from tailings management technologies, it is possible to compare not only the differences in current practices between the countries but also to observe how well the current regulatory frameworks are able to capture the elements of the so called optimal regime.

As a conclusion, this study takes part in the contemporary discourse related to the quest for greener and more innovative mining practices by claiming that effectively managed tailings can yield wide-ranging benefits both for the industry and societies in general. This requires smartly implemented regulatory goals and the right balance of carrots and sticks for making unwanted, and not completely unavoidable, tailings both valuable resource repositories, and major liability and risk factor for companies if not managed properly. Better tailings management practices would also have a far-reaching spatial and temporal applicability as they would benefit not only the present mining communities but also those affected by the historical legacy of abandoned mine sites and poor tailings management practices.

End-of-waste Products and Internal Market

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Waste products tend to replace the primary raw materials in industrial production more and more often. Using waste-based raw materials help the actors of industry to cut down their costs of delivery of the raw materials, storing the materials, the processing and waste management of the operation. In addition, using waste-based raw materials also supports environmental interests. However, the use of waste as a raw material of industrial production is not merely in legislator's hands: the development challenge of increasing efficient material use and reducing the production of waste is also in the hand of the market operators. The utilization of waste-based materials requires a functioning market besides the legal framework, so that it can be guaranteed that waste material *de facto* end up in recycling processes.[4] Sole legislative framework is probably not enough to create a rapidly growing functioning circular economy. [5]

In my presentation I will focus on examining the position of waste-based products and materials that have ceased to be waste due to the article 6 of the Waste Framework Directives (2008/98/EC)[6] from the point of view of the European Union's internal market and competition and antitrust law. In the presentation I will examine the position of end-of-waste products and materials compared to primary products and material produced from virginal raw materials. Is also must be noted that the fact whether the product or material is waste or an end-of-waste products matter substantially when it comes to internal market. Thus, it is very important how the end-of-waste regulation is interpreted when it comes its market, market potential and demand. Even the utilization-wise undeveloped waste streams will benefit a lot from a in-depth analysis of the matter.

Even thought waste is handled in the same way as products when it comes to free movement of goods in the internal market,[7] the waste-status has its own effects in its free movement and marketing. When a substance ceases to be waste after an

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[4] See COM (2014) 398 final, p. 2–3, 12–13; COM (2011) 571 final, p. 10; COM (2005) 666 final, p. 15.

[5] See Koivisto, Janne: Materiaalihyötykäyttö ja kansainväliset jätteensiirrot. Ympäristöjuridiikka 1/2007, p. 9, 16; Halme, Minna – Heino, Erja – Anttonen, Markku – Kuisma, Mika – Konttoniemi, Nea: Materiaalinsäästön palveluista liiketoimintaa – Kohti jätteiden synnyn ehkäisyä. Helsinki 2005. Suomen ympäristökeskus 2005, p. 8.

[6] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, OJ L 312, 22/11/2008, p. 3–30.

[7] C-2/90 Comission v. Belgium (1992) ECR I-4432, kohta 28; C-221/06 Stadtgemeinde Frohnleiten v. Bundesminister für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (2007) ECR I-9643.

end-of-waste regulation it must be handled in the same as it was a similar product. The typical characteristics of an end-of-waste product could however affect its position in the market and applicable legislation.

In the light of internal market and competition law in would seem that an end-of-waste product belongs to the same market as a similar product made out of virginal materials. Considering the end-of-waste criteria set in the article 6 of the Waste Framework Directive the premise is that the product fulfils the quality criteria to be similar with the corresponding primary products. In situations where the waste-based products can substitute a virginal product or material, it is clear that the two options must be considered similar considering the ban on the discrimination in the internal market. Therefore, virginal products and materials can only gain market benefits from their own beneficial characteristics, and not from never having a waste-status.

When defining markets it would seem that the primary products and end-of-waste products have the same market considering the competition and antitrust law. This is peculiarly clear when an end-of-waste product comes to substitute a primary product. Considering the principle of mutual recognition, these rules apply to national end-of-waste legislation in addition to EU wide end-of-waste legislation. If a substance has an end-of-waste status in one member state it should be clear that the products cannot be legally transferred into waste in other member states

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