International Round Table on Materials Criticality

IRTC Round Table

In-use stocks and secondary supply of CRMs

July 7, 2019 - ISIE2019, Beijing

The International Round Table on Materials Criticality, IRTC (www.irtc.info), is an internationalization project funded by EIT Raw Materials which runs from April 2018 to March 2020 and consists of 23 researchers from Europe, US, Canada, Australia, Japan, Korea and China. The project aims at advancing criticality assessment on a global level. In four Round Table workshops and joint publications, research on differences and commonalities of different approaches on criticality as well as considerations about its implementation in industry and policy-making shall be fostered and advanced. Awareness towards materials criticality, and its crucial role for a circular economy, shall be raised by creating visibility at established conferences with a diverse audience and high impact in research and industry. A first Round Table took place as a side event of the „Resources for Future Generations" conference on June 19, 2018 in Vancouver, Canada, with the title „How methodology determines what is critical". A second Round Table was conducted in the context of the Ecobalance conference in Tokyo, Japan on October 9, 2018, with the title "Criticality and the Circular Economy", and a third one on "How industry manages criticality" on March 14, 2019, in San Antonio, Texas, in the framework of the TMS Annual Conference and Exhibition.

The fourth International Round Table on Materials Criticality took place on July 7, 2019 in connection to the Conference of the International Society for Industrial Ecology (ISIE) 2019 in Bejing, on "In-use stocks and secondary supply of Critical Raw Materials, especially REEs."

Morning Session

The meeting started 08:30 h Beijing local time (CST, GMT+8), with a series of talks about the topic. After the welcome of IRTC project coordinator **Alessandra Hool** from ESM Foundation (Switzerland), Prof. **René Kleijn** from Leiden University (Netherlands) presented on **"Metal supply constraints for a low-carbon future".** His talk focused on the need to close material loops and move towards a circular economy, and put a highlight on the potential of reuse and recycling as mitigation factors for carbon emissions. An analysis of advantages and challenges on the use of

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renewable energies was presented. Main challenges were found to be related to material constraints for the development of low-carbon energies, to high prices compared with energy based on fossil fuels, and to the need to store the produced energy in a non-continuous production cycle. Risks of supply disruptions are highest in extraction and refining stages of the supply chain. Special considerations should be given to local factors related to natural disasters, social and geopolitical issues that affect the supply chain, and considerations about the economic effects of metals co-production. Opportunities for the use of renewable energies are mainly connected to alternative energy carriers such as hydrogen, decentralization of energy production and the development of "smart" energy grids. The need to analyze the whole demand for specific materials required in the production of renewable energy was discussed. After this opening presentation, Dr **Anthony Ku** from China's National Institute for Clean and Low-Carbon Technology (NICE) talked about **"The impact of technological innovation on critical materials risk dynamics"**. Dr Ku explained the need for updated and available datasets to assess the origin of materials and trade flows around the world. Data is usually imperfect and the currently available data incomplete, hence no perfect knowledge is possible. Instead, the goal is to get the best insight possible under the circumstances. Since economic considerations are the main driver for the inclusion of resource use concepts from the industrial perspective, companies are mostly interested in keeping a steady supply with controlled costs, while in parallel improving the efficiency of manufacture processes. Examples are the use of LEDs replacing fluorescent light bulbs, a technology that has a significantly lower REE materials intensity; efforts are being made to reduce the need of these metals and substitute them for others that have a better performance or are less critical. Making forecasts about emerging technologies is a challenge and requires the ability to anticipate incremental changes. Dr **Peng Wang** from the Chinese Academy of Science, on behalf of Dr **Weiqiang Chen**, presented **"The story of neodymium and europium".** Dr Wang showed that China is the historical main supplier of Nd and Eu in the global market, but still faces various challenges in its rare earth industry. With help of material flow analysis, there is an increasing concern about the implications of the production of these materials: rare earth is a basket of 17 elements, and they are co-mined with other metals. There exists a gap between the supply and the demand of Nd in China and an oversupply of Eu due to the decreasing application. Important considerations concern the by-production surplus which might make recycling undesirable, and increase the production cost of other elements. It was discussed how by-production dynamics impacts material criticality. In a talk on the **"Nexus of critical metals and Sustainable Development Goals",** Dr **Keisuke Nansai** from the National Institute of Environmental Studies, Japan, showed the development of a regression model between SDG indicators and critical metals indicators. The results were presented for the year 2004 to 2013. The study will be followed up by the Round Table participants for further discussion. Comments from the audience included the questions whether it would be possible to assess the correlation in terms of positive impacts, and if there is a possibility to update the results to years after 2013. Prof **Ester van der Voet**, Leiden University, talked about "**Environmental risks and challenges of anthropogenic metals flows and cycles"**. Current discussions in the material flow area revolve around how to assess the impact of metals extraction, refining and use in the environment. Most life cycle assessments are developed from a cradle-to-gate perspective, and it is challenging to model use phase and end-of-life scenarios. A method developed by Prof van der Voet and colleagues uses OECD resource scenarios to develop a first comprehensive global assessment of the

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environmental impacts of metal extraction while considering present and future supply. Seven major metals (Fe, Al, Cu, Zn, Pb, Ni, Mn) were fully assessed; CRM (considered as minor metals in this study) are described as challenging to assess. Recycling and substitution were suggested as impact mitigation factors for these materials, but challenges such as insufficient and expensive recycling technologies were presented. Main comments from the audience referred to the fact that many recycling technologies do not yet provide the raw materials quality required for current production systems and the necessity to provide incentives to promote secondary sourcing. Ms **Eliette Restrepo**, from the Swiss Federal Laboratories for Materials Science and Technology (Empa) talked about **"Supporting critical metal recycling policy with stocks and flows data: Practical experiences and feedback from stakeholders. The case of car electronics in Switzerland"**. The presentation gave an overview of different projects carried out at Empa aimed at supporting Swiss car recycling policy. Over more than five years of research, the knowledge about material composition of car electronics and car shredder outputs has increased. For example, by means of chemical analysis and material flow analysis models it has been possible to establish that the quantities of metals such as gold and neodymium found in cars are in the same orders of magnitude than those in natural mines. This implies that cars are a potential source for critical metals in the future; with most of the metals being found in the car electronics. However, the amount of data and system's understanding needed increases as more specific recycling solutions are explored. Aspects to be considered before implementing policies that promote recycling of car electronics are: i) the current dynamics in the car recycling system (dismantling of electronic devices, separation of materials after shredding, treatment of shredder residue), and ii) the future trends in car electronics. An initial suggestion is to monitor the car technologies put on the market in order to develop recycling strategies in a timely manner before the cars reach end of life. Comments from the audience focused on the diversity of vehicles on the market and future trends such as electric vehicles, hybrid cars, and autonomous cars. Questions were raised regarding the criteria that will be used to prioritize or promote certain recycling strategies over others. Prof **Gang Liu**, University of Southern Denmark, presented on **"The physical economy of critical materials and criticality assessment"**. Critical materials are frequently characterized by an increasing demand for new technologies and a limited availability around the globe. Prof Lui presented the pyramid developed by the MinFuture project (www.minfuture.eu): a framework for monitoring physical economy, assessing the drivers of resources demand, and understanding future scenarios. Discussions revolved around examples of resources for renewable energy technologies and the continuous search for good solutions on CRM recovery (wind turbines, energy storage). Relevant factors to consider are the existence of big in-use stocks of CRM but lack of mainstream recycling processes to recover them. Dr. **Jinder Jow** from China's National Institute of Clean and Low Carbon Energy provided a **"Status report of potential critical materials recovery from fly ash in China"**. Dr Jow presented a summary of the production of fly ash in China. Estimations indicate that a single Chinese company produces more fly ash than the whole United States. Inventories of recovered CRMs were presented, such as Gallium and REE, as well as examples of further potential for secondary sourcing. Currently, new industry standards are developed regarding test methods and the assessment of critical elements in fly ash. Comments from the audience generated a discussion around costs for the mentioned sourcing technologies, taking into account that costs vary around the globe but the chemistry of the processes does not.

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Prof **Danhui Yang**, Chinese Academy of Social Sciences, presented ways **"Towards Mitigating the Supply-demand Tension of Critical Minerals: 4R by Market-oriented Measures".** Based on current demand and supply trends there is an increasing concern for access to CRM around the globe, involving issues related to trade and geopolitics. Prof Yang showed a summary of results for criticality indicators for 22 materials used in 19 applications from the Chinese perspective. A framework to assess the price elasticity of supply and demand was presented based on the traditional market mechanism; however it is unlikely for it to be consistent with social, political, cultural and/or environmental goals. Price dynamics could exacerbate scarcity because of the oligopoly on REE. Currently, despite having a big share of the global supply, China is not able to determine prices in the global market. Prof **Chang Wang,** Central South University, China, talked about **"How to mitigate the supply constraints of by-product metal for clean energy technology"**. The talk introduced the challenges around by-product metals and their classification as critical by several countries. It is considered that overall reserves of critical metals are sufficient to meet demand for a long time, but actual availability depends on economics, trade disputes and geopolitics. The main supply concern for materials used in electronics is the "daughter-parent", or co-production dependency between metals. This was exemplified by the system boundaries of Gallium industry chains as highlighted by a Material Flow Analysis.

Afternoon Session I: Junior Researcher Awards

The second part of the meeting started 14:30h Beijing local time (CST, GMT+8). It started by presentations of the awardees of the IRTC grant for junior researchers. Three awardees had the opportunity to present their research online. First, Dr **Christoph Helbig**, University of Augsburg, talked about "**Supply Risks and Dissipative Losses".** Dr Helbig provided a methodological proposal on the assessment of material dissipation, whereas multiple indicators related to materials criticality are equally weighted to obtain an overall criticality measure. Higher dissipation indicates a higher criticality of the material. Dr Helbig obtained the data on dissipative losses from dynamic material flow analyses, considering a technical or economically impossible recovery or recycling. Ms **Jane Mwaba Mulenshi,** Luleå University of Technology, presented her work on "**Secondary sources of critical raw materials".** This study on secondary mining from historical tailings is presented as part of the REMinE project (LTU Sweden, U.Porto Portugal, INCDMRR Romania); the project aims to characterize as well as develop effective separation and extraction processes for these sites from an economic and environmental point of view. Multiple sites were selected to take samples for the experimental analysis; preliminary results show potential for tungsten recovery. Proposed processes are gravity separation, magnetic separation and flotation. Posterior work will be focused on flotation process for tungsten, fluorspar and copper recovery, as well as optimization of gravity and magnetic separation processes. Finally, **Maria Fernanda Godoy Leon,** Ghent University, presented on **"Assessing the circularity of Co: prediction of the flow of Co in society through eight applications".** The presented project has as main objective to assess and

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map the flows of cobalt in different applications on a 40-year forecast, focusing mainly on secondary sources. Motivation for this work is the increasing demand of cobalt for new technologies and the transition towards a low carbon energy grid. The model assumes constant exports; the initial values are taken from input-output tables. A sensitivity analysis of all variables is planned for the future.

Afternoon Session II: Round Table discussion: In-use stocks and secondary supply of CRMs

Alessandra Hool opened the Round Table discussion with the question: ***"Which technologies will contribute in the future most to an increased use of REE and other CRMs?"*** Four main areas of application were identified: (i) Energy and transportation: An increased use of critical raw materials for batteries (energy storage) of renewable energy is expected. Some (complex) materials that are not high priority right now, such as carbon fiber and graphite, could become critical because of this development. (ii) Information and Communication Technologies (ICT): It is estimated that lifecycle from training an algorithm in Artificial Intelligence are equivalent to the lifecycle CO_2 emissions of two internal combustion engines. REEs will continue to be relevant because of their optical properties. (iii) Aviation: China's main 2025 roadmap includes an expansion of the aviation industry. There are several critical elements used in planes, such as yttrium and rhenium. (iv) Military Applications: It is not possible to obtain immediate data about this industry due to the sensitivity of the information.

"Are CRM a stepping stone in the urban mining discussion or are they more of an afterthought?" Two main types of stocks were identified to be considered in the urban mining question: (i) The built environment, referring to big flows, mainly in construction (gravel, steel, cement, etc.). Recycling rates in this sector are normally high and relevant for future urban development (housing and construction). Main challenges are the low costs for primary concrete, and the difficulty to design recycling processes that are profitable. (ii) In-use metals: another potential type of urban mining is related to the recovery of precious metals, CRMs, REEs and other materials/elements used in energy production/storage. The main challenges addressed for these are in the design processes for the technologies in which the materials are used (dismantling, recovery, durability, replacement, recycling).

The discussion around the question ***"What are the main drivers for recycling of REEs in China?"*** started with the statement that environmental benefits from recycling and secondary sourcing are somewhat clear to all stakeholders; however, the economic benefits of these alternatives are questionable. The discussion expanded to examples of other metals: e.g. for gold and copper, relatively easy, profitable and well standardized recycling processes facilitate the development of a second sourcing network; however, the same cannot be said of CRMs such as indium, tantalum, and others. The question of the quality of recycled material was introduced in the discussion: downcycling and upcycling. Clear examples from the Chinese context are the use of old car batteries for powering other electronics: some companies are refusing to use recycled or refurbished components due to safety considerations, since it might be unsafe or risky to use secondary materials which might be of lower quality. An example of a success story of refurbished

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electronics or recovered/recycled materials is Caterpillar, who markets second hand machinery "same-as-new". The company has developed programs to recover and refurbish engines, which can later be sold at a lower price but with assurance of good quality. This program started with an economic incentive, and this business model is considered to be successful for 50 years already.

"***What are the main challenges for the secondary supply of REEs in Europe?"*** An immediate answer to this question was to have control over waste flows, specifically having the opportunity to recycle and recover before exporting to other regions. This requires a solid understanding of where in-use stocks are located and when they will become available. Another challenge is the access to and ownership of in-use stocks; producers will have more incentive to recycle if they maintain ownership of the equipment. A further main challenge identified at the Round Table is the cost-effectiveness of secondary supply; it is not possible to know if recycling technology could develop well enough to reduce current recycling/recovery-related costs such as labor, upscaling, energy use, and others. Solutions were also presented: advanced recycling fees, extended supplier responsibility, social business models. Ideally, these solutions would be promoted by policies.

"*What kind of data is missing in Europe to enable comprehensive secondary sourcing?*". Although it is expected that the 4 highlighted application areas will use CRMs, it is difficult to gather data on the composition of products used for these technologies (frequently, numbers are being "recycled" from past publications). Access to CRM use might be provided via material sciences studies and/or the review of patents. The PROSUM project (EU H2020) appears to be an opportunity for obtaining information about WEEE composition in the European Union, as it – among others - analyzes consumer electronics, batteries, and mobile phones. Other contributions referred to the inclusion of other sectors in the list of priority areas, such as progress on autonomous transport, which is currently underrepresented but increasing. Participants also discussed the issue of proprietary information. The common opinion was that companies already are aware of all the materials that are used in their products, but that there is no single master database or inventory that collects the bill of materials from all companies. Big data and machine learning might be future approaches to understand how elements are moving in the economy. Involving governments in criticality studies was suggested as a feasible approach to the problem. Governments have showed interest on understanding inventories of materials present in EV or machines used for renewable energy production and storage. It was mentioned that from the government perspective, military and strategic applications are relevant, therefore it is possible that the US and China might be starting to analyze trade information and to track materials throughout the supply chain.

The evaluation of CRM use in the future brings another challenge*:* When a company invests large amounts of money to upscale a laboratory process, a the timespan for a technology to become accessible on the market usually takes several years – for some sectors such as aviation even up to two decades. Assumptions passing such a long period would be too speculative. It was initially mentioned that sometimes it is not necessary to go further in time to predict secondary sourcing scenarios; it is frequently sufficient to understand how technologies are being developed right now and prepare recovery technologies after the current technologies on the market become obsolete. As a summary, it was stated: "We should monitor what we put on the market". A

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participant from the table agreed that this would be the case if we only focus on secondary sourcing; however, it wouldn't be sufficient when assessing, for example, future demand or understanding the energy transition; this is important especially because some applications will still be available during the next decade, but some others will require new CRMs that are not being considered as critical at the moment.

A last main question was introduced by the panel: ***"How can standardization contribute to increasing secondary supply and circularity?"*** Main objectives of standardization of recycling processes are the minimization of losses and costs while keeping the quality of the materials/components. Current efforts in the ISO committee for standardization of recycling processes in the region are being led by China, Korea and Japan; the main foci are collection practices, product design and upscaling of industrial processes. China is currently implementing systems to promote the collection of waste electronics in order to increase recycling rates throughout the country. The closing statements of the day, finally, circled around the implementation of carbon taxes and inclusion of externalities in prices of materials; these externalities do not only have effects on single nations, but have to be taken into account on a global level.

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