IRTC Round Table in Tokyo on "Criticality and the Circular Economy", October 9, 2018

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. 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".

The second International Round Table on Materials Criticality took place on October 9, 2018 in the context of the Ecobalance conference in Tokyo, Japan. The title of the second Round Table was "Criticality and the Circular Economy". After a welcome from Keisuke Nansai (NIES), the concepts of the Circular Economy, the Sustainable Development Goals, and social implications of resource extraction were introduced by Ester van der Voet (Leiden University), Guido Sonnemann (University of Bordeaux), and David Sussman (New York University), respectively. Furthermore, several speakers were invited to give more insight into the Japanese, Korean, and Chinese perspectives on material criticality and the Circular Economy. Kotaro Shimizu (Mitsubishi) presented the Japanese strategy on the procurement of mineral resources from a policy perspective. Hiroki Hatayama (AIST) explained the role of the Japanese R&D agency NEDO in Japan's critical raw materials strategy. The JOGMEC's approach to assess and mitigate material criticality was presented by Yoshihiro Kojima (JOGMEC). Shinsuke Murakami (University of Tokyo) gave an overview on the history of Japanese criticality assessments. A Korean perspective was provided by Kyoung-Mook Lim (KIRAM), who presented the Korean Circular Economy Framework. Min-Ha Lee (KITECH) presented Korean and international efforts in the standardization processes to facilitate the Circular Economy. The Chinese perspective on critical and strategic materials and the circular economy was provided by Weiqiang Chen (Chinese Academy of Sciences).

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The afternoon session started with a summary of the first Round Table, with the topic *„How methodology determines what is critical"* by Alessandra Hool (ESM Foundation). Dieuwertje Schrijvers (University of Bordeaux) presented the progress in the publication that is being drafted based on the outcomes of this first Round Table. The winners of the IRTC Research Grant were given the opportunity to present their work as well. Joanna Kotnis (TU Delft/Leiden University) presented her research on the recycling potentials of Cobalt in The Hague, and Björn Koch (University of Oldenburg) presented the work he did together with Sebastian Tiemann on indicator choices for criticality assessment.

The second half of the afternoon session was dedicated to the Round Table discussion. The participants of the Round Table were Weiqiang Chen (Chinese Academy of Science), Jo Dewulf (Ghent University, Belgium), Roderick Eggert (Colorado School of Mines & Critical Materials Institute, USA), Hiroki Hatayama (AIST, Japan), Atsufumi Hirohata (University of York, UK), James Goddin (Granta Design, UK), René Kleijn (Leiden University, the Netherlands), Min-Ha Lee (KITECH, Korea), Kyoung-Mook Lim (KIRAM, Korea), Keisuke Nansai (NIES, Japan), Guido Sonnemann (University of Bordeaux, France), David Sussman (New York University, USA), Tanya Tsui (TU Delft, the Netherlands), and Steven B. Young (University of Waterloo, Canada). Participants of the audience were also invited to engage in the discussion. The discussion was moderated by Alessandra Hool (ESM Foundation, Switzerland) and Dieuwertje Schrijvers (University of Bordeaux, France).

The Round Table discussion opened with an exploratory question: **How do the Circular Economy and Criticality relate to one another?** Roderick Eggert explained that criticality is a set of tools for risk assessment and mitigation. Criticality assessment fundamentally takes the perspective of a user of materials. This user could be a company, a manufacturing sector of a nation, or developers of a specific technology, such as wind turbines or photovoltaics. The Circular Economy, on the other hand, is a model about how materials should be used in a city, in a nation, in the world. The CE could be considered as one of the responses to criticality, which could allow for mitigation of risks associated with criticality. There are three ways to reduce criticality: production of more primary material, wasting less, or using less by developing substitutes. In that sense, CE enhancements are one of three options to decrease criticality. Jo Dewulf pointed out that there is no commonly agreed definition of the circular economy. Some definitions focus on the circular aspects, the flow of materials, and technical aspects of reverting, recycling, recovering and refurbishing. In this context, there is a match with CRMs. If the emphasis is put on the *economy* part of the CE, for example with regard to business models, the link with CRMs is less clear, since goals might overlap gradually, but not necessarily – it might be economically viable, for example, to focus on keeping mass metals in the cycle and disregard metals that only make small amounts of the product mass, volume and/or value. For

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experts working with criticality it would be important to know which circular strategies are relevant for specific CRMs.

If criticality is a risk assessment tool, **what types of risks are generally assessed by a criticality assessment?** Several criticality assessments, such as the methodology of the European Commission and the Japanese and Korean approaches assess risks related to the economy. Kyoung-Mook Lim explained that different types of criticality could be relevant according to different situations in countries. Korea has a large manufacturing industry, which is why the country is interested in the economic risks of raw materials. This is also reflected by the Korean strategy towards the Circular Economy. Roderick Eggert stressed that criticality assessments do not necessarily have to focus on economic risks. Other types of risks are environmental risk, such as included in the Yale methodology, or reputational risk. These are all different types of criticality. The common theme in a two-dimensional world is that there is the supply risk on one axis and the impact on the other axis: this impact could be social, environmental, or economic. David Sussman explained that social factors can also contribute to supply risks as these could affect the supply of minerals. He emphasized the need to first make a prioritization of agenda goals - for example, whether a social dimension should be considered - before developing calculating protocols for criticality assessment. Similarly, environmental issues can be a source of supply risk, according to Weiqiang Chen. Environmental impacts have been an issue in the global Rare Earth production in the '90's and early 2000 and are still a big problem in China. However, Jo Dewulf argued to keep criticality assessment more focused: although different types of risk could be included in the assessment, the key question of criticality should be whether the risk factors lead to a supply disruption in a certain time window. Atsufumi Hirohata noted that the response of speculation seems to be missing from criticality assessments although it could be of high interest for companies and governments. The company Seagate, for example, ran into this problem when it wanted to purchase iridium for their hard drives, while investors were holding the material back and driving up prices.

Can criticality be used as an indicator to prioritize circular economy activities? From the discussion it became evident that the circular economy could have different types of objectives. René Kleijn noticed that the term CE often is used as a synonym of sustainability. In a long-term sustainability perspective, where materials are available for economic development without compromising the environment or society, a CE is needed, also for critical materials. James Goddin argued that circular models are not necessarily environmentally beneficial, as the circular economy is in principle just an economic model for making better value out of material extraction. Guido Sonnemann brought up that the creation of jobs, which is also reflected by the SDGs, could be a further driver for the CE. This is for example relevant for regional CE strategies in France. Jo Dewulf illustrated the fact that the circular economy can have different

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objectives by the example of one of his PhD projects: they used both environmental performance and criticality as criteria to optimize the performance of take-back schemes and material recovery of batteries in Belgium, which lead to different optimization strategies. Keisuke Nansai pointed out that criticality assessments do currently not consider the potential of urban mining. The NEDO method aimed to reduce the risk related to mining, by making Japanese companies co-invest in new mining sites. This is currently their main activity to decrease criticality. However, Japan has a big potential for urban mining, although there are currently no recycling technologies and the collection ratio is not very high. The first step to make urban mining viable is to set goals for 100% collection rates, and then invest in technologies to recover the materials. We could use the instruments of territorial mining assessment to quantify urban mining levels and integrate this into criticality assessments to motivate the government and industries to encourage urban mining. Guido Sonnemann highlighted that mitigation through actions are a question of priorities where to invest: strengthening urban mining on a regional level is an investment in the national economy, in contrast to investing in mines in other countries. Thus, there is a need of cost-benefit considerations of mitigation options, and the different loops of the circular economy are part of it. The criticality assessment methodology is very relevant for this, as some methods consider recycling rates, such as the European approach. Such methods enable to evaluate whether recycling decreases the criticality of materials.

What policy mechanisms could be put in place to decrease material criticality via the circular economy? Min-Ha Lee explained that there are activities of the Korean government that enforce the use of recycled resources by law, similar to the EU. New products should include a recycled content. Via this way, Korea stimulates the circular economy. But although there is a high mitovation to recycle, recycling is currently economically not profitable. Shinsuke Murakami (University of Tokyo) added that in Japan, too, the material industry has to report the recycled contents. There are studies available on the amounts of scraps collected by the material industries. But these requirements are more aimed to support the material industries rather than to implement the circular economy: materials with small recycling rates, such as CRMs, are not reported. There are also targets in place for specific recycling rates for some recycling schemes like automobiles. While such recycling policies could make materials less critical if CRMs are included, Steven Young considered it plausible that they could also pose a regulatory risk to manufacturers and designers. If there would be requirements specified in regulation, companies could not be able to meet those circularity requirements, which would make the use of the affected materials difficult for those companies.

How do we deal with trade-offs regarding reducing ecological impacts and saving resources? James Goddin shared that Granta Design has conducted studies to identify how a company's

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exposure to price volatility could be reduced by circular practices. However, circular activities, but also other risk mitigation strategies such as substitution, could lead to additional costs, additional environmental impacts, increased use of hazardous substances, or other unwanted effects. A company operates in a tightly interrelated system, and optimization of one aspect affects many others. We need to understand on how these interrelations work in order to integrate circular principles in product design, consumer perception, and the use of products. Keisuke Nansai pointed out that with the transition towards a circular economy, risk related to mining countries can be decreased, but the supply risk might then be posed on the recycled materials, especially if the materials are recycled in developing countries under poor environmental and social conditions. If such factors are considered, recycled materials could become more critical – an effect which is currently not represented in criticality methods. Weiqiang Chen suggested that if we would internalize environmental costs into material prices, market mechanisms would avoid certain types of risk shifting. James Goddin added that if resources would be diverted away from primary production, people who rely on income from mining will be negatively affected. However, it is challenging to integrate social metrics in an assessment as these are very specific to a supply chain. Jo Dewulf doubted whether criticality methods should represent the complex trade-offs mentioned. Although trade-offs are important in a life cycle thinking perspective, this might be beyond the purpose of risk assessment and risk mitigation as targeted by a criticality assessment. Trade-offs also exist among the objectives of criticality assessments. René Kleijn said that there might be some sectors in which one would like to have CRMs available, like the energy transition, while other technologies using CRMs also thrive. But whereas in the renewable energy sector prices are crucial, for the newest version of a mobile phone it doesn't really matter how much a few milligrams of CRMs costs. This industry will be willing to pay the price while it is problematic for the social challenges that we are facing. Guido Sonnemann pointed out that this relates to the potential drivers of criticality assessments. The CRMs that are used in electronic gadgets create new markets and thus stimulate economic growth, while those used for renewable energies could add to decreasing GHG emissions. These are two very different perspectives, where criticality assessments summarizing general "risk" are mostly not differentiating. In most cases, economic importance or industry importance are used the main factors related to policymaking, such as in the European and Japanese approaches.

Which types of indicators are relevant for the evaluation of a transition towards a circular economy?

The Ellen MacArthur Foundation and Granta Design have in 2015 developed a circularity indicators system. James Goddin recalled that these indicators initially included criticality, environmental impacts, and sustainability factors, which was all combined in a formula that provided a single number. However, this number did not help in identifying solutions.

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Therefore, they separated the circularity by applying a simple mass flow equation showing the amount of virgin material that is used and the amount of waste that is generated. This can then be compared to hazardous materials, critical materials and environmental footprint and used to assess trade-offs. Tanya Tsui raised the point that we need to distinguish more between different levels of recycling and downcycling. For example, the building industry could declare to be 80% circular, thanks to the use of recycled material in tarmac. Alexandra Pehlken (University of Oldenburg) added that recycling targets are formulated in units of mass, which puts a focus on the recycling of the bulk materials that often exclude CRMs. For example, the recycling rate of wind turbines is currently quite high, due to the fact that the mass represents mostly concrete and steel. If recyclers should extract CRMs, there should be an indicator that better reflects these materials. Guido Sonnemann agreed that the definition of recycling rates is very important. In Europe the focus is on the recycling of the whole product. With a product focus, there is no differentiation between materials which all count in the final mass-based recycling rate. On the other hand, Japan seems to differentiate more between the recovery of materials. It might be easier to measure circularity with a material approach. However, the UNEP report "Metal Recycling – Opportunities, Limits, Infrastructures" from 2013 suggested that a product perspective would be more suitable if the aim of recycling is to decrease environmental impacts. Nabeel Mancheri (KU Leuven) brought up that recycling rates of materials can be different in different sectors, such as construction and mobility, rather than being dependent on the material itself. Also, if the inner loops of the circular economy are followed (e.g. reuse or remanufacturing), a sectorial perspective might be more appropriate than a material perspective, as suggested by James Goddin.

What is the current potential of the CE to decrease material criticality? Weiqiang Chen noticed that the discussions about the circular economy are currently mainly driven by base materials: cement, papers, plastics, iron, copper. They have high in-use stocks and end-of-life flows and are relatively easily recycled. CRMs often have small in-use stocks and end-of-life flows compared to future trends of technology development. The CRMs are often not the main material in a product but rather companion materials. CRMs require different recycling techniques, and these are currently not economic. This should be brought into the CE discussion. Guido Sonnemann added that the challenge is dissipative use: most CRMs end up in other metals that are being recycled. If recycling is part of the mitigation strategy, then the question is how to minimize these dissipative flows. This is an organizational and technological question. In Japan and Europe, research is going on to respond to this challenge, with a focus on materials with very low recycling rates. James Goddin said that the risk response is very different in situations of small volumes or large volumes. A lot of criticality methods that we use today don't really differentiate between these. People seem more concerned about material

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use if it reflects large quantities in single products, than when large quantities are dispersed over many products.

Can circularity help to reduce the dissipative use of CRMs? René Kleijn pointed out the importance of the consideration of recyclability in the product design phase, especially during the development of large-scale technologies like solar cells and wind turbines which should be deployed in the next couple of decades on a very large scale. Recycling would be feasible for magnets in wind turbines: the materials can be located, they are present in relatively large amounts, the magnets are large in size and there is knowledge how to recycle them. These factors are different for solar cells: recycling technologies for solar cells are in their infancy while at the same time these technologies are deployed on a large scale. The layers of solar cells are glued together, which makes recycling very tricky and almost impossible. There are technologies that work without gluing which makes recycling easier. It should be considered today how to physically include CRMs in products in a way that they can be reused and recycled relatively easily in the future. Philip Strothmann (FSLCI) highlighted that the 2013 UNEP report taught us that when mixing metals that don't belong to the same family, it becomes very difficult or even impossible to recycle them. Unless design happens with the "Metal Wheel" in mind, the CE cannot work. Alexandra Pehlken confirmed that today in the manufacturing industry, this is not done. It is hardly possible to dismantle a battery of a smartphone or computer, and the mixing of metals puts limits on the recyclability. Furthermore, it is challenging to receive composition data from manufacturers. René Kleijn believed that it will be very difficult for designers to only stick to the combination of metals that is suitable for recycling. There should be more incentives for companies to make products more recyclable. These incentives could be extended producer responsibility or take-back schemes, so manufacturers have to recycle their own products. However, even in that case they might find it too expensive to extract the CRMs. On the other hand, eco-design could compromise the functionality and competitiveness of the product. Besides, the degree to which recycling could decrease criticality could be limited. Hiroki Hatayama illustrated this by explaining the Japanese situation: currently, despite the implementation of several recycling regulations, the recycling rate of CRMs is low. However, even if the recycling rate would be 100%, it would not be sufficient for Japan, because many products are exported. For example, even if all the materials embedded in domestic vehicles would be reused or recycled, this can only cover half of Japanese demand. James Goddin suggested that there might be opportunities with regard to circularity models focusing on retained ownership. This could be relevant for electrical vehicle batteries where batteries are not bought but leased independently of the vehicle. Although international trade makes the implementation of such models challenging, several options could be explored.

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Besides recycling, what other circularity strategies could be used to mitigate the criticality of materials? James Goddin believed that the real opportunity for critical materials is not necessarily recycling, but rather reuse: the real value in products such as magnets and batteries is not just the material value embodied in the products, but also the additional value put in by manufacturing. Tanya Tsui agreed that if recycling is impossible, reuse and refurbishment are still alternative options. Layla van Ellen (TU Delft) emphasized that design for the circular economy includes design for disassembly and design for flexibility. In the construction sector in Japan, for example, a lot of wooden connections are used without the need for glue or bolts, which makes parts reusable. James Goddin added that the CE does not necessarily require a whole system's change. There have been several small disruptive models in specific sectors, such as automobiles. New business models such as product-service-systems could lead to a smaller number of vehicles on the road, which could make materials less critical. Guido Sonnemann agreed that the functional economy could increase the substitutability of CRMs, as substitution could be measured on a functional level of the technology rather than a material level. Tanya Tsui added that, to facilitate the inner loops, more social expertise and new business models are needed. If the target is increased reuse of e.g. a solar panel, a new business that resells solar panels has to be found, and the creation of policies will be needed that make the reused solar panels fit to the building requirements. There are more social mechanisms relevant for the inner loops than for the outer loops. On the other hand, new technologies that facilitate the CE could make new materials critical. For example, the use of sensors facilitates urban mining by keeping track where imported materials are. Materials important for these technologies could become critical. Layla van Ellen added that Blockchain could also be used to transfer knowledge on product specifications and material content, while protecting the confidentiality of manufacturing companies. This is already applied e.g. by the startup Circularise from the Netherlands.

What factors could influence the successful implementation of CE strategies? Alexandra Pehlken raised the point that we need more training of the younger generation. Teenagers don't know the reasons for separating packaging waste. The next generation is not trained in resource management, and there is a big opportunity to teach them, e.g. via serious gaming models. David Sussman added that human behavior and the social system in which we use products would also be interesting to consider on a product level: for example, how often we replace our cell phone. James Goddin confirmed that design is not only about technological issues, but also about esthetic and sentimental values. There is a behavioral aspect of the circular economy which could be addressed via business models, for example by selling, leasing or the way products are marketed.

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