IRTC Round Table on "How Industry Manages Criticality"

San Antonio, Texas, March 14, 2019

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 took place in the context of the Ecobalance conference in Tokyo, Japan on October 9, 2018, with the title "Criticality and the Circular Economy".

The third International Round Table on Materials Criticality took place on March 14, 2019, as part of the TMS Annual Meeting 2019 in San Antonio, Texas. The title of the third Round Table was "How industry manages criticality". During the morning session, speakers were invited to give presentations about the relevance and application of criticality assessments by different industrial stakeholders. After a welcome from Alessandra Hool (ESM Foundation), Roderick Eggert (Colorado School of Mines and the Critical Materials Institute, USA) presented the management of the critical minerals in the US economy. Min-Ha Lee (Korea Institute of Industrial Technology, KR) showed how the Korean industry secures critical raw materials. Nikolaos Michailidis (Aristotle University of Thessaloniki, GR) gave insights into the use of raw materials for additive manufacturing and David Jarvis (HIPTec AS, USA) presented how the manufacturing sector deals with critical raw materials and environmental impacts. Armin Reller (ESM Foundation) displayed how the assessment of criticality over the supply chain can be a competitive advantage for companies. James Goddin (Granta Design Ltd., GB) elaborated on the issues which companies face in regard to raw materials data. Christina Meskers (Umicore, BE) provided an industry perspective about critical raw materials with a particular focus on recycling.

After welcoming the Round Table participants and the audience (on-site and online) to the afternoon session, Alessandra Hool (ESM Foundation) briefly introduced the IRTC project, which holds a variety of Round Tables on different topics related to material criticality and uses the outcomes of these discussions for joint publications. She also referred to the follow-

up plans of the project which aims at providing guidance for industry on how to assess criticality. Further, she presented the program for the afternoon session:

1. Presentation of Dieuwertje Schrijvers (University of Bordeaux), showing first results of the dialogue with people from industry at the TMS conference about their perception on criticality (e.g. their awareness regarding materials criticality and the relevance of criticality in their company). These preliminary results should also serve as an input for the further Round Table discussion.
2. Two short presentations of ongoing research in CRM related projects by IRTC travel grant awardees, Jair Santillan (University of Bordeaux) and Marcus Berr (Empa St. Gallen).
3. Round Table discussion and reception.

Dieuwertje Schrijvers presented preliminary results of a survey which was conducted during the TMS conference and aimed at identifying best practices and knowledge needs of the industry regarding the management of raw materials criticality. The survey was subdivided into four different categories.

1. General information about the company and the representative (e.g. type of company, representative's role in the company)
2. Materials used by the company
3. The familiarity of the company with the concept of criticality
4. Management or investigation of supply risks and the mitigation of supply risks in the company

During the conference, the survey received 36 responses, mainly from representatives of manufacturing companies operating in each part of the supply chain (early supply chain stages such as mining and refining as well as end-of life treatment stages). Most of the participants were sale representatives, who are possibly not the best informed about raw material criticality or supply risks within the company. However, most of the respondents stated that they have at least some knowledge about the material use within the company and know their direct suppliers. The responses showed that amongst the respondents, familiarity with criticality and related methods is rather low, due to a lack of relevance for the company and/or the lacking request of the customers. Supply risks and fluctuating prices were, however, deemed relevant for the company. Nevertheless, the respondents showed little knowledge about up-stream suppliers, and the assessment of raw materials criticality was not considered to be a competitive advantage by most. Some company representatives believed that they are reasonably aware of their critical materials.; others stated that their participation in the survey has made them more aware about the relevance of the criticality concept. From a comment by the audience, it was recognized that a question targeting long-term agreements of companies with suppliers would be beneficial for further investigation. Furthermore, the need was stressed to consider that companies might be impeded in their answers by a competition law or knowledge restrictions regarding their competitors.

The winners of the IRTC Research Grant were given the opportunity to present their work as well. Marcus Berr (Empa St. Gallen, Switzerland) presented his research on addressing raw

materials supply risk indicators in Life Cycle Sustainability Assessment, and Jair Santillan (University of Bordeaux, France) elaborated on the assessment of potentials for recycling to mitigate raw materials supply risk.

The second half of the afternoon session was dedicated to the Round Table discussion. The participants of the Round Table were Roderick Eggert (Colorado School of Mines and the Critical Materials Institute, USA), James Goddin (Granta Design Ltd., Great Britain), Atsufumi Hirohata (University of York, Canada), David Jarvis (HIPtec AS, USA), Christina Meskers (Umicore, Belgium), Guido Sonnemann (University of Bordeaux, France), Min-Ha Lee (Korean Institute of Technology), Steven Young (University of Waterloo, Canada), Armin Reller (ESM Foundation, Switzerland / University of Augsburg, Germany), Jair Santillan (University of Bordeaux, France), Layla van Ellen (Delft University of Technology, the Netherlands), and Orlando Rios (Oak Ridge National Laboratory and Federation of European Materials Societies (FEMS), USA). 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: **For which economic sectors are critical materials relevant?** Roderick Eggert explained that the concept of critical materials generally applies for all types of sectors. In particular, it should be focused on sectors where the material and system designs become more complex, because a greater number of raw materials are utilized with added complexity. For many of these materials, relatively low historical experience is existing, their markets are rather small and fragile and it is difficult to anticipate when supply disruptions possibly occur. Additionally, sectors of concern are those with high demand growth rates, since this can lead to unexpected situations for the supply situation: for example aviation, transport, electronics and computer. Min-Ha Lee, whose research addresses the assessment and management of criticality by the Korean industry on a national level, observed that many OECD countries face equal challenges in terms of material criticality. The focus in criticality assessment on a national level nowadays is more on the long-term supply risks, while private companies are mainly concerned about their profit.

Are there common perceptions on criticality or supply risk for certain economic sectors? Orlando Rios explained that he observed two different ways how industries deal with criticality. One way is that certain industries make larger investments when there is a secure supply. Another way is that, prior to their investment, industries investigate how the supply chain might look like and make an effort to diversify it. In this way they have different sources and possibilities of supply if disruption incidents occur.

How does a company experience a supply disruption and what are the consequences for the company? James Goddin stated that consequences can vary, while an obvious one is the revenue loss caused by, for example, the price volatility of a certain element. The effects of volatile prices can be quite significant, especially when a company uses large volumes and has a

dispersive use of certain materials. Another type of risk depicts uncontrolled changes in the supply chain. One example is the removal of hazardous substances from the supply chain due to specific regulations. This represents a risk for industries, which rely on these substances and consequently cannot access and use them anymore. Another example is a change in the composition and performance of a material by a supplier without informing the downstream suppliers about these changes. These two occasions might result in failures along the supply chain.

The next question concerned the mentioned risk of price volatility and the risk mitigation strategy of diversifying the supply. **Does the diversification of suppliers protect a company from price volatility?** Orlando Rios pointed out some commonality between these two. In order to deal with price volatility he observed an approach where industries look at the acceptable tolerances of material impurities, which still enable to achieve the right performance. The relaxation of some of the limits regarding for example impurities, the appropriate setting of performance matrixes for materials and the simplification of recycling add a certain flexibility to supply chains and makes the material more robust to supply changes. James Goddin confirmed that the regulation of material performance is of particular importance in terms of protection against price volatility. He pointed out that when a constitute of an alloy increases in price, the producer of this alloy uses less amounts of this constitute in order to lower the investment costs, but stays within the tolerated boundaries of the allowed compositional range. However, this compositional change will anyhow have an impact on the performance of the alloy. Steven Young mentioned that there are reactions of industries directly as consequence of price spikes. In Leiden, Netherlands, it was investigated that magnet makers provided magnets which accepted a wider performance tolerance in order to decrease the utilized amount of Rare Earth Elements (REE) in the magnets during the REE crises. Furthermore, an increasing focus is put on geographical risks from suppliers. In some cases, companies believe that they have multiple suppliers for particular products without realizing that those suppliers are all buying their product from one company or that those suppliers are all located in the same area. He added that climate related supply risks are becoming increasingly important when investigating the locations of individual actors in the supply chain. In some areas, supply disruptions may occur due to weather events, global warming or rising sea levels.

Are certain materials more critical due to their high importance on the performance of devices? Atsufumi Hirohata affirmed and stressed that this is especially the case for the magnetic memory sector. While, in his opinion, the first priority of these industries is to reduce the size (thickness and dimension) of the employed elements, their second priority is to replace the critical raw materials. These industries mainly recognize the criticality through the price of the material; the price of iridium for example varies significantly throughout the year. However, the introduction of replacement materials typically takes more than 5 or 10 years.

Taking up the result of the survey that many companies are not aware of materials criticality, the following question arose: **Is there enough of the right information available and the necessary information accessible?** David Jarvis believed that there is sufficient data available, and he pointed out that quite a lot of information was published recently, as for example in the UNEP report. Nevertheless, values of data for particular elements have large ranges, which might be due to geographical differences or different processes that are involved. More detail of how the data of specific materials was acquired would be beneficial to give the industries a certain confidence in the use of these data, for example for their Life Cycle Assessments (LCAs). LCAs and used data do not have to be completely precise, but they should provide a good order of magnitude and show general trends. He concluded that the data is there, but needs slight improvements and regular updates over time due to the dynamic, ever changing situation. Guido Sonnemann highlighted that the data availability challenges with regard to criticality are the trade flow data, which are not available in LCA databases. While the publicly available trade data bear a relatively high uncertainty, the access to databases containing private data are very expensive.

Are there restrictions or difficulties from a company perspective to share not only life cycle data, but also other data on specific material flows? Christina Meskers confirmed that there definitely exist restrictions, especially in small markets, because providing a high transparency of the company data reveals confidential and competitive information. Thus, one of the challenges is to understand how much transparency needs to be provided by the companies and how much information can be derived from LCA data about the supply chain processes. She believed that to balance this is one of the keys to determine the sustainability of industries. In addition, she clarified that data gathering takes a lot of effort, uncertainties are connected to the collected data and the discovery of the right methodologies is often not straightforward. James Goddin referred to the uncertainty and value ranges of data and argued that it is not necessary to have a perfectly quantified answer when it comes to critical substances and critical materials. Instead, it is necessary to identify where the hotspots of the risks are, prioritize these risks and address the identified essential risks through business processes. It is often sufficient to have a general understanding where the highest risks occur, even if data for the calculation of the risk are relatively uncertain and a full quantification is not possible. Therefore, a risk assessment might be sufficient, if it shows which risks are higher, compared to other ones. Christina Meskers agreed that in some cases quantification is not necessary. For example, a gut feeling might be sufficient to determine risks due to trade barriers, and information about the location of the major world production is enough to examine the risk of supply concentration. She stressed that, due to the changes in data from one day to the other, an early warning is important for dynamics that are often not possible to quantify. James Goddin clarified that it is necessary to reflect the uncertainties of the data and indicate them, in order to avoid misuses of data. Orlando Rios mentioned that some industries publicly show with LCA data that their product is environmentally friendly. An example is the study of Rio Tinto on "greener aluminum", where recycled materials and green power are used for production. Armin Reller pointed out that it is important to know the supplier structure. This

means awareness of where the products one is buying are coming from, knowledge on the number of suppliers, and if these are reliable. Some companies, which sometimes have too little knowledge about their supply chain, even perform a vertical integration in order to increase their control and to gain strategic advantage. While it is too complicated to have knowledge about the whole supply chain, it is essential for companies to find out which parts of their supply chain are important and provide a strategic advantage. Steven Young pointed out that companies mostly know who their direct suppliers are, but have little knowledge about the suppliers on the second, third and following tiers. The companies extracting the critical materials are several tiers downstream and it is unusual for Original Equipment Manufacturers (OEMs) to know those suppliers. A possibility to better identify the actors along the supply chain is a questionnaire approach, where a survey is sent from the top tier companies along the whole supply chain to the bottom tier companies, asking primarily where the material is coming from. However, the response rates, as achieved in an example application of this approach, were in the order magnitude of 1% to 2%. Even through aggregation of multiple company responses, only a relatively small number of smelters around the world could be identified. It has been an expensive exercise for these industries to figure out where their materials are coming from and consequently be able to achieve some transparency in their supply chain. To the question of Dieuwertje Schrijvers whether the approach was worth the effort and money for the companies, Steven Young answered that for some companies it has been more rewarding than for others. It was beneficial for OEMs, who make certification and standardization decisions and have a relatively high reputational risk. After such a supplier analysis, they could as good as possible demonstrate to which suppliers of the assessed materials their contractual arrangements go back. The benefit was lower for smaller companies and enterprises further up in the supply chain due to the high costs of this approach. Only companies were included in the questionnaire exercise that follow good practices. However, it remained unclear which companies had to make an effort and expenses to change their practices substantially beforehand in order to participate.

The next question concerned the issue to choose the right methodology to evaluate impacts and criticality. **Do companies, for example in the US, use some published criticality methodologies, such as the method of the National Research Council or other types of criticality methods?** Roderick Eggert explained that most criticality assessments observe two basic criticality factors, the supply chain risk and the impacts to a supply disruption, but then use a variety of methods, ranging from formal to informal or quantitative to qualitative. The reasons for the variations in their methods are their different priorities in terms of the three different types of risks. These are the risk of physical material unavailability, the risk of high material prices, uncertainties and price volatilities and the reputational risk. The latter is especially important to high-profile companies such as OEMs in electronic consumer goods. However, for many companies this risk is relatively less important than the other two types of risks. Due to the different prioritizations of the risks, different companies use various indicators for their assessment. James Goddin also noticed that different companies choose different indicators to measure their supply chain risks. He mentioned that in some parts of organizations it is

desired to aggregate the indicators to a single number, which shows a high or low risk. However, when it comes to people who actually have to deal with risks, the desire is higher to keep the risks separate in order to understand them individually. It is crucial to identify the hotspots and understand how to respond to risks. If the different types of risks and the sources of the risks are not identifiable, a response becomes difficult. In the beginning of a risk mitigation process, first the hotspots are identified and then the details of the upstream supply to these hotspots are investigated. Guido Sonnemann confirmed that it is interesting for companies to understand these multiple risks, but he also gave the example of General Electrics who was able to aggregate these various, regional different risks through economic evaluation, i.e. estimating a price for the risks. Some companies applied this monetization approach already for evaluating the environmental impacts. He raised the question, whether the clients of Granta Design have shown an interest in economic evaluation for their risk or whether they are managing their risks in-house in this way. James Goddin affirmed seeing this approach and gave the example of Rolls-Royce, where critical materials risks were tied to the internal, financial risk management system, by understanding the level of particular materials risks and their responses. Most advanced engineering companies have a well-developed risk management framework, which is typically linked to financial implications of design changes or supply chain failures. The critical material risks can be inserted into that framework as another category of risks that the business has to manage. Armin Reller added that he was working with a company which produces highly complicated machines and has a market share higher than 50%. This company has no stocks but receives inputs to and outputs from the production on a daily basis. Consequently, the risk that production is not in time can be manifold, caused by strikes or accidents for example. Within their company, a Systematic Investment Plan (SIP) scheme is applied, where the whole supply chain is covered to ensure that at least two different suppliers are always existing for each supply route in order to decrease the supply risk. In this way, the company knows where the material is coming from, has information about supply disruption incidents and can react to these disruptions. Since all the suppliers are managed in one SIP scheme, the company has the full control over an on-time production and the quality of the resource and the raw material. He pointed out that this is a risky but successful business.

Who in the company should be aware of the different types of risks, which concern different areas? David Jarvis believed that the management of risks is not assigned to a single person in the company, since it is a broad topic. It rather needs an appropriate amount of people, who are directly in charge of risks. For example, people in procurement, in supply chain management, in product development and in R&D should be involved in the management of risks. In large companies often a risk manager is employed, who synthesizes all the information and informs the board of directors about the risks, who make then the decision how to deal with these risks in the company. Guido Sonnemann explained that in smaller companies only a small amount of persons are responsible for risk management, while in big OEMs a whole department takes care of the risks. He further pointed out that sustainability and criticality aspects are often managed in the same department of a company and that life cycle management provides some ideas how to deal with criticality and sustainability. Further, he argued

that the engagement of design for environment, product development and R&D departments are indeed relevant, but nowadays it gets increasingly important to have the right procurement. The sales department has to be informed about criticality challenges, which, as it could be seen in the survey executed during the conference, has often not been done so far. An internal training about criticality aspects is missing for sales people. Roderick Eggert proposed that criticality management, which is in his opinion fundamentally concerned about risks, is the responsibility of the chief financial officer of a company, who takes care of the organizations risks. Christina Meskers put forward that the products sold by different companies are diverse and the sales are often not from business to end-consumer. In many cases, criticality is not the primary selling argument but rather sustainability aspects are such as energy efficiency of a machine for example. She also commented that the different types of risks, which the criticality aspect covers, are spread out over the company. Supply chain risk for example is rather interesting for persons who purchase the materials for the product, while environmental risk is of concern for someone from the environmental department. However, in the end, an experienced person in the company is needed to evaluate risks based on all the information available. Layla van Ellen added that the consumer also desires a product, which is ethically produced by companies. She argued that an ethical production is also part of criticality, because criticality covers social and political aspects as well. Christina Meskers clarified that in this sense the business-to-consumer and business-to-business relationships should not be mixed up, because they differ from each other. In the business-to-business relationship domain, a business partner cleaning, which includes the investigations regarding sustainable sourcing and the code of conducts for example, is carried out before the choice for a supplier is made. She mentioned that businesses build a strong relationship with their suppliers and it would unbalance the system a lot, if they would switch their key suppliers every year. James Goddin agreed that there are differences in the relationships and he stated that child labor for example rather has to be considered as a risk in the business-to-consumer than in the business-to-business relationship. He deferred to the initial question and argued that the risks have to be systemically imbedded in all stages and escalated appropriately. Therefore, the investigation of risks should be started with the screening of new material at the design processes and be followed by additional investigation along the business processes in order to find alternatives to the risks. Orlando Rios mentioned the concept of neutral risk and distributed risk, which implies that the risk is shared across the stakeholders. In case of fluctuation in the price, the fluctuation is built into the actual cost of the component.

On the one hand, a lack of awareness is existing regarding the footprint of the critical raw materials in many companies and on the other hand, these critical raw materials are needed for cleaner future production. **Are customers or businesses willing to pay an additional price in order to have a sustainable supply chain?** James Goddin has experienced cases where consumers were willing to pay more for certain aspects such as ethical sourcing or environmentally beneficial products. The public expectation for companies to incorporate such sustainability aspects is also growing and the businesses are aware of this expectation. If companies address these aspects voluntarily or proactively, they are able to decide how to manage them

by themselves. However, as soon as they are forced by legislations, they have no choice to decide for alternatives. Orlando Rios pointed out that products from the "green aluminum" production and the production of rare earth magnets in Germany have a premium price due to their more sustainable production and several customers prefer them in their buying decision. Steven Young argued that companies with a business-to-consumer relationship are primarily not concerned about the question whether the consumers are willing to pay more, but rather about their reputational risks. He made the example of Apple, which invested in the preparation of a list of all first tier suppliers in order to provide a degree of transparency and confidence to their customers. Companies with a business-to-business relationship are primarily interested in having knowledge about their customer, counter-parties and suppliers. For these companies it is necessary to know about the practices, business partners and the risks of their suppliers. He pointed out that the purchase from companies, which commit financial crimes or disregard the antiterrorism law for example, can have a big impact on the business relationship. Further, he gave two examples of vertical integration cases, which have been done to secure the purchase of fundamental materials.

James Cotton (Boeing) from the audience raised the fact that OEMs and small companies work a lot with standards and they are interested in managing risks. However, he experienced that there is no settled criticality methodology to use for companies. Thus, he asked the following question. **Is there any effort moving towards a standardized method that might be released as a standard through a standard organization to describe a recommended way of doing a criticality assessment, so that industry and academia can all talk on the same benchmark?** Alessandra Hool mentioned an upcoming publication of a paper about best practices in criticality assessment that should provide a framework to set some standards in that regard. Armin Reller replied to the question that it is not possible to quantify all the needed indicators and it is difficult to determine the risk causalities, meaning the relationships between clusters of risks, for individual products. Therefore, the competences of experienced people, who know about the supply structure and the risks, are crucial in order to take care of criticality within the company. Guido Sonnemann highlighted that there is a difference between industrial standards and the standardization, which would have to be agreed on for the criticality assessments. The governments, who mainly carry out criticality assessments, might look into parameters concerning the main locations of the industries in the supply chain, their material ownership and their access to materials. Additionally, he mentioned that criticality might be added in the ISO guidelines. James Goddin believed that the closest example to a standardization system for critical materials is a template for the reporting on restricted substances, which starts to be adopted by industries. Such templates might help to retrieve data from supply chains. He also put forward that the types of data is a challenge for standardization. When making an assessment using the global production and the world bank governance figures, the results are the same, no matter where the company is located. However, the assessment results would be different for a Chinese company compared to other companies around the world. The reason is that most of the world supply is located in China and Chinese companies, in contrast to other companies, have no issues with accessing these materials. He added

that, unfortunately, there is no concrete way of adjusting these figures to account for different geographical situations or different mitigation methods, yet. Steven Young argued that there are no standards for critical materials because criticality is a situational and business specific situation. Each business has their own context, within which for example the physical sourcing is carried out and the economic regulations are set. However, in the field of sustainability and reputational risks many standards are existing (e.g. standards for conflict minerals, new standards for responsible aluminum and steel etc.). Supply chain standards, which concern the content of the commodity along its supply chain, are also existing. In conclusion, a lot of standards are in place showing a clear direction of beneficial resource use, but they are not suitable to apply for each individual situation of company businesses.

What should be the role of governments in helping industries to manage their individual criticality? Min-Ha Lee answered that the handling of criticality is the main objective of the Korean government in order to support the industrial development. The profit of the industries is very important to maintain some of the Korean country's values. Guido Sonnemann added that a committee for strategic metals has been set up in France as a support for industry demands. This committee combines government and research and discusses publicly funded research projects that aim to support for example criticality assessments and technological developments for recycling and substitution. James Goddin pointed out that governments could notably support industries by funding the provision of data. While the USGS is quite well funded, higher funding would be beneficial for the British Geological Survey. The data matrices of these databases are heavily dependent on the acquisition of decent data. Huge data gaps and uncertainties are still existing for specific elements as, for example, the rare earth elements. Steven Young clarified that the governments have also used stockpiling to interfere or support the availability of raw materials for industries. He brought up the examples of Korea, China and the US, where stockpiling is or has been used by the governments. Christina Meskers added that the role of the government should also be to enable and support trade between different regions of the world. Additionally, recycling, as a supply risk mitigation possibility, should be supported and facilitated by governmental policies as an additional source of supply. Armin Reller explained that the ESM Foundation was founded out of the question whether it is necessary for Switzerland to stockpile. This question was raised because Switzerland was entirely dependent on resource imports after the second World War. He also mentioned the idea of global metal policies, where merely the functions of metals are leased. Steven Young brought up the suggestion to use critical materials as a store of value that is available globally. David Jarvis argued that the governmental role is the funding of research projects for combinatorial research and computational metallurgy, which provide solutions for the avoidance of critical materials in the future. These projects are typically not funded by industries, because of their high risk and capital expenditure.

Alessandra Hool drew the conclusion that the answer to the question how criticality is managed in industries covers a variety of aspects. Whereas not all companies pay specific attention to criticality, especially larger OEMs observe these developments usually closely and often

have an incentive for increased transparency in view of potential reputational risks. Publicly available criticality assessments e.g. provided by Governments might be used for a broad screening, but detailed weighting of individual risk is usually part of an internal evaluation process. More important than an overall scoring is a differentiation into factors or type of risks in order to inform on suitable mitigation measures.