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IRTC-Business workshop summary

Critical Raw Materials: The driver for the new low-carbon economy: How can we make supply sustainable?

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Video available at https://www.youtube.com/watch?v=-eDJzCrE5bA

Presentations available at https://unece.org/sustainable-energy/events/unece-resource-management-week-2021-12th-session-expert-group-resource

The Chair of the UNECE Expert Group of Resource Management (EGRM), David McDonald, introduces the workshop with a few preliminary thoughts. As the economy becomes greener, Critical Raw Materials (CRMs) become more and more important. The future of energy production will be dominated by these solid minerals as it is today by oil and gas. If demand for CRMs continues to increase as expected, also the environmental impacts of their mining will become more and more important. New smart mining processes and recovery methods could help to secure supply and make it more sustainable. The UNFC (UN Framework Classification for Resources) and the UNRMS (UN Resource Management System) emphasize the importance of circularity for a sustainable (CRM) resource management.

Milan Grohol (DG Grow, European Commission): CRM supply: current and future challenges

The department DG GROW deals with different raw materials: minerals, metals, wood, natural rubber, and hydrogen. DG GROW performs regular criticality assessments for the EU economy. The last analysis was published in 2020 and identified 30 critical raw materials (bauxite, lithium, titanium, and strontium were added to the list compared with 2017, and helium was taken off the list). The EC is concerned about the supply of raw materials that is concentrated in a few countries only, such as rare

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earth elements (REEs) and magnesium from China, iridium from South Africa, niobium from Brazil, beryllium from the United States, but also a concentrated supply within Europe such as hafnium from France, and strontium from Spain. The EC mapped the raw material use in important sectors such as (among others) aerospace/defence, electronics, mobility/automotive, energy intensive industries, renewable energy, and digital technologies. A flow chart (Figure 1) shows the use of CRMs in technologies within three strategic sectors: renewables, e-mobility, and defence & space. It visualises the complexity of the supply chains and technologies competing for critical materials (e.g. wind turbines and traction motors for rare earth elements). A missing element in the screening is the use of REEs in hard drives and electronics in the ICT sector.

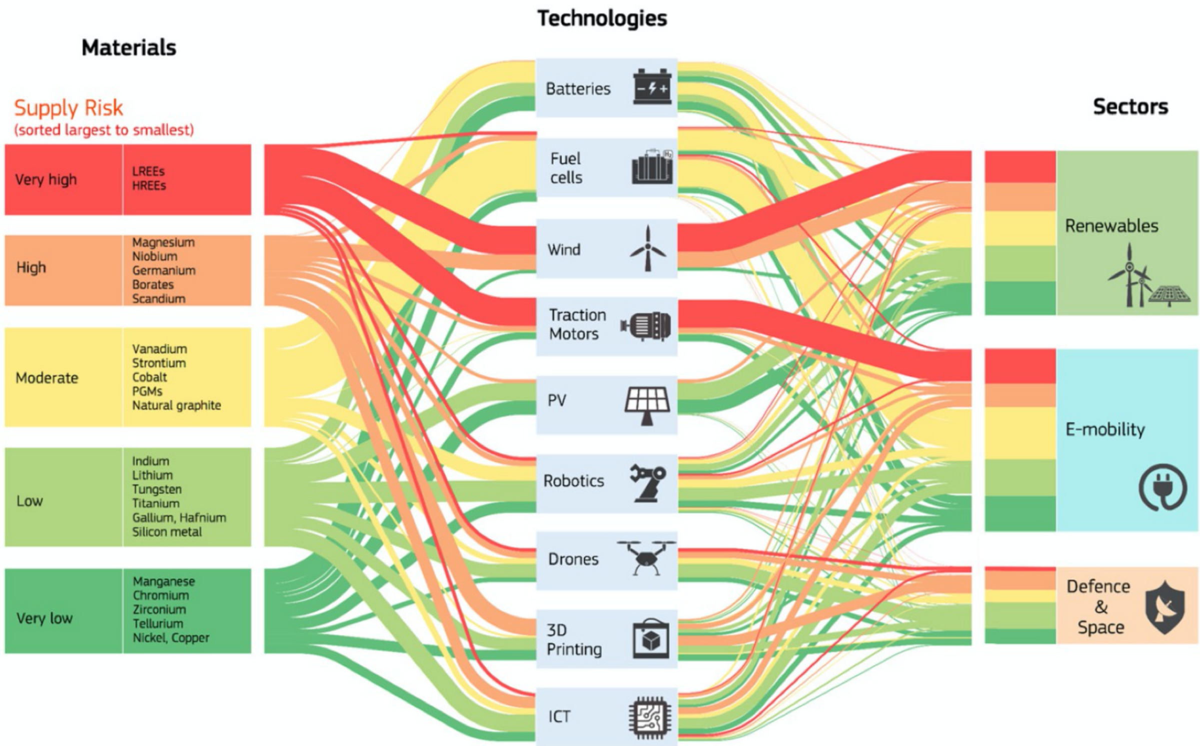

Figure 1: European Commission: Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020.

For the first time, the EC made a projection of raw material needs by 2030 and 2050 (corresponding to the 1.5 degree target for climate change), which are relevant time scales to consider investments now. For applications in mobility and renewable energy, lithium demand is expected to increase by a factor of over 50 compared to current total demand. Cobalt and graphite demand could increase by a factor of over 10. Also the demand for REEs, which are currently mostly imported as semi-finished products, will strongly increase. Not only the criticality of raw materials was screened, but also of processed materials, components, and assemblies. In the case of lithium batteries, the EU is dependent on import in all stages in the technology. Similar conclusions are valid for electric motors and generators.

The EC formulated an action plan to decrease EU's raw material dependencies:

1. European Raw Materials Alliance

2. Develop sustainable financing criteria for mining
3. Research and innovation on waste processing, advanced materials and substitution
4. Map the potential supply of secondary CRM from EU stocks and wastes
5. Investment needs for mining projects that can be operational in 2025 (e.g. based on UNFC classification, which allows for the comparison of different projects from an economic, environmental, and social point of view)
6. Develop expertise and skills in mining
7. Deploy Earth observation programmes for exploration, operation and post-closure environmental management of mines
8. Develop research and innovation projects on exploitation and processing of CRMs
9. Develop strategic international partnerships to secure CRMs supply
10. Promote responsible mining practices for CRMs

CRMs are gradually replacing fossil fuels as the backbone of the green energy and digital transition. Therefore, it is important that UNFC and UNRMS integrate the life cycle management and circularity considerations of CRMs into their systems. The EGRM could benefit from expertise in mineral and anthropogenic working groups as well as EU-funded initiatives, such as IRTC and SCRREEN2.

Magnus Ericsson (RMG Consulting, Sweden): Mining's contribution to national economies – critical raw materials in transition to a low carbon future

Based on three studies funded in the United Nations system it can be concluded that there is a large potential in mineral resources for emerging economies in the current transition period.

One study focussed on 4 factors: contribution of mining to GDP, export contribution, exploration, and mineral rents contribution to governments. Among developing/middle income countries in 2018, mining contributed most to the national wealth in the Democratic Republic of the Congo (DRC), Suriname, Burkina Faso, Mali, Guyana, Papua New Guinea, Guinea, Peru, Botswana, and Chile. Over the years, during the period of the supercycle in the years 2000-2014 (when supply was lagging with rising demand), the importance of mining increased structurally (e.g. in Brazil and Sweden). We might be at the start of a new supercycle, which emerging economies could benefit from. The aforementioned emerging economies in which mining contributes largely to national wealth have however a minor contribution to global mine production. In 2018, coal mining contributed most to the value created at the mining stage worldwide. This could be problematic for emerging economies that rely on coal mining, if future demand decreases. Focussing on metals, iron ore, copper, and gold represent two thirds of the total value created at the mining stage.

In a study on metals used in batteries, an index was created based on the following factors: known resources in all countries of the world, current production, country exploration, the mining contribution index, and the existence of an established mining industry. Among the emerging economies, the countries that have the largest potential to benefit from increased demand for battery metals are Bolivia, Morocco, Burkina Faso, Cote d'Ivoire, DRC, Zambia, Zimbabwe, Tanzania, Madagascar, Kyrgyz Rep., Philippines, and Papua New Guinea.

Metals needed in the ICT sector accounted only for 0.1% of the total value obtained by mining in 2018 (excluding REEs). Production of ICT metals (beryllium, gallium, germanium, indium, REE, selenium, tantalum, tellurium) is dominated by the US, China, and Australia – emerging economies provide a minor contribution. This makes ICT metals less of a growth opportunity for most emerging economies.

Emerging economies can benefit from the unique opportunity of the expected future growth of demand for metals and minerals in a low-carbon future by the increased need for mining, while avoiding the environmental and socio-economic pitfalls and difficulties. The European Union, the European Commission, and European countries have a role in transferring technologies and best practices to emerging economies. Mining should be further developed in the (e.g. African) countries that can economically benefit from this, rather than focussing on marginal deposits in Europe.

Gavin Mudd (RMIT, Australia): Critical Raw Materials and Sustainable Supply: Recent Research for 21st Century Needs

The world needs reliable, responsible, and sustainable supplies of critical minerals to help address climate change and achieve progress on the Sustainable Development Goals (SDGs). One of the main problems for the sustainable supply of CRMs is a lack of data on the global supply potential. The USGS makes global estimates of reserves (resources that are profitable to mine in the current economic context), but they have to deal with a lack of data. This lack of data could be due to the evaluation of "substitute elements", which are elements (e.g. cadmium, germanium, and indium) that substitute for the primary economic minerals within the ore. For example, indium is a substitute element in minerals such as sphalerite (ZnS). When zinc is mined, perhaps 1% of the value could be obtained by indium. But as the value of the mine will be mostly determined by zinc, the indium content is ignored. Cadmium (which is needed in certain solar panels) is seen as a toxic element or impurity element, which is why the cadmium content is not reported with the same level of detail as other elements.

These CRMs are small markets, with comparatively low value in mining, and are supplied by only a handful of companies or countries. Therefore, there is a lack of recognition of CRMs in resources and mine products. This lack of data is often confused with a lack of supply potential. At RMIT, research is conducted in obtaining more information about the supply potential of these CRMs. As many of the CRMs are mined as by-products, there is no information on primary deposits. However, based on data on the primary elements, which is relatively complete, estimates can be done about the potential supply of CRMs. Geochemical relationships and geochemical databases are used to establish correlations between reported elements and CRMs – the "Werner method".

Given the nature of critical minerals commonly being reliant on primary metals, and the extensive global endowment of these, it is clear that the world has an equally extensive endowment of critical minerals – both primary deposits (e.g. REEs, Li) and by-products (the rest). For example, regarding rhenium (a by-product of molybdenum), there is a linear correlation between rhenium content and molybdenum content in economic reserves. Even though data is lacking on the availability of rhenium, the data that is available on molybdenum can be used to extrapolate and estimate the availability of rhenium. Based on such relationships, also large amounts of Australian resources of gallium, germanium, hafnium, tellurium, selenium, indium, and strontium could be inferred.

Even when focusing on the main metals, the amount of resources has been demonstrated to be dynamic. During mine production, reserve estimates become more accurate and sometimes increase, and additional resources are identified as well. There is however a trend of declining ore grades for copper, nickel, lead, zinc, and many other metals. How much can be extracted from a certain amount of ore depends on a variety of factors such as how refractory the ore is, possible processing technologies, existence of impurities, and recovery rates. But in general, lower ore grades mean that an increasing amount of ore needs to be processed to obtain the required metals. This results in increased environmental impacts.

A recent study on global nickel deposits showed that deposits should not only be evaluated based on the grades of the primary metal – nickel laterites with high nickel grade and magmatic sulphides with lower nickel grade – but the contents of copper, cobalt, and PGMs could have similar cumulated economic value if all the extracted metals are taken into consideration. The economic profitability of mining is influenced by the grade but also by the type of mineralogy. Higher grade mineral deposits could be sulphides or oxides, whereas lower grades could be granite or limestone. Extraction from these lower grade deposits requires a much larger amount of energy. The change of mineral type is indicated by Skinner's Mineralogical Barrier.

The principal CRM challenges are understanding recoverability, global market dynamics (especially rapidly evolving sectors like renewable energy, electric vehicles, specialty alloys, electronics, etc.), market power, trade flows, and implications of these. Australia is a strong supplier of CRMs, and has even the potential to further scale up production. The production of scandium, for example, is currently concentrated in the Philippines. However, Australia has a strong potential to increase scandium mining. Mining was limited due to limited demand, but the application in Al-Sc alloys for solid oxide fuel cells for the hydrogen economy is a promising market. Scandium can be found in nickel laterites, which are present in Australia. Known numbers on resources and reserves demonstrate that Australia would be able to meet global scandium demand.

The production of REEs, which are also increasingly used in modern technologies (defence, renewables), is currently dominated by China. Australia currently mines REEs from Mount Weld and Brown's Range. Other active projects are the production of REEs as by-product at Toongi or from Heavy Mineral Sands (HMS). Australia has another large deposit of rare earth elements, the Olympic Dam. However, this deposit is mostly sub-economic. Furthermore, the specific availability of REEs (heavy or light) is relevant as well to determine economic feasibility.

Australia has also a large potential to scale up the production of lithium. The amount of economic reserves has increased strongly in the past few decades. Currently, Australia supplies around 70 kt of lithium out of 100 kt worldwide. The value of lithium exports surpassed the value of uranium, which is a turning point in the perception of the Australian mining industry.

Besides increased supply from mining, RMIT is also investigating the potential of extracting critical raw materials from Australian tailings. Furthermore, much work is still needed on the circular use of CRMs. From a policy point of view, there is a lot to be done to help to increase the value extracted from the metals.

Luisa Moreno (Tahuti Global Inc., Uganda/Canada): Critical Raw Materials – Capacity Building in Supplying Countries: What is needed?

Not all globally identified resources are economic to extract at current prices. Therefore, Tahuti Global Inc., based in Canada, supports government and investors with finding and valuing strategic materials mines and projects worldwide. The company also supports junior mining companies with project financing.

There are over 40 materials that have been identified as critical by the US, Japan, EU, and Canada. China is the largest producer of more than 20 of those. Canada is the largest supplier of only potash and caesium. China, which is smaller in landmass than Canada, has a more developed production of critical materials. They are less reliant on international alliances and coalitions and more self-sufficient. One strategy of China is to develop their own technologies in mining, processing and refining. As an example, China (and similarly, Russia) modified the Bayer process to refine lower-grade domestic bauxite, whereas western countries rely on the import of higher-grade bauxite.

The Chinese government has a hands-on approach with regard to the development of national production of resources. Resource companies are often controlled or partially owned by the government. The government offers aid (grants, low-interest loans) to the industry along the supply chain (miners, refineries/processors, and end-users). Production quotas are implemented to control internal production, and export quotas allow for control of resource access. In the last few years, many research hubs and centers were funded by the Chinese government at home and internationally, including in Africa.

The EU followed a similar strategy as China with regard to the automotive industry, particularly the battery supply chain by offering grants to manufacturers. One of the aims of the European Raw Materials Alliance is to access EU funding opportunities and financing sources for the development of mining /refining projects inside and outside Europe. As some of the projects are technically challenging and investments may not yield returns, the term "aid" applies here. Such measures are a necessity to catch up with the developments in China and become self-reliant on critical materials. Both in the EU and in Canada, support is provided to the automotive industry, but mining companies also need aid. Critical materials attract less than 5% of the global exploration budget, and these projects are usually financed through capital markets. Canada has the highest number of listed companies exploring or mining critical materials, including lithium and graphite. However, most projects lack funding. In Australia, the Lynas Rare Earths Ltd was successful in developing their rare earth project due to the support of Japan, more or less in line with the Chinese model. Japanese companies provided loans to Lynas and are extremely patient and tolerant with regard to the financial performance of Lynas and their ability to serve the loans. In the US, rare earths are mined by the company MP Materials, and subsequently sent to China for further processing. Before MP Materials, the rare earth deposit was owned by Molycorp. This company went bankrupt because their creditors were not as patient as in the case of Lynas. In summary, most of such companies are funded through the stock market. Only a small amount of the funding is spent on exploration, and the competition to receive this funding is high.

Also raw material processing facilities are in need for funding. Processing of critical materials is very complex and often energy intensive. This makes it difficult for developing countries, which do not always have the necessary power infrastructure to support such projects. The CAPEX of material processing plants can be around a billion dollars, similar to the total size of the annual market of certain materials. With a typical expected investment payback time of 4 years and an internal rate of return of 20%, investing in processing of critical raw materials is not always feasible.

Therefore, governments should collaborate to increase the discovery and advancement of critical materials around the world, for example, as envisioned by the US Energy Resource Governance Initiative (ERGI). Especially international coordination is needed. Governments should collectively invest in infrastructure, as large resources of critical materials are in remote areas, e.g. in Northern Canada and Africa. Canada has many resources, but with a relatively small population, such investments are difficult to bear. Governments should collaborate to invest in mineral projects via low interest loans, equity investment, grants, lower taxes, joint ventures, public-private partnerships (PPPs), etc – the EU Raw Materials Alliance (ERMA) is a good example of PPPs. Global supply chains should be supported by offering aid to resource companies, refiners and processors, metal makers, fabricators, etc. Resource-rich countries should avoid resource nationalism, but more effort should be made to bring benefits to countries that are supplying minerals. Finally, investing in R&D and skill training centers is needed to build the require technical workforce and stay competitive.

Carlos Peiter (Centro de Tecnologia Mineral, Brazil) : Niobium as a strategic metal for Brazil

The Brazilian research institutions CETEM, IBICT, and EESC-USP, the European Commission/Joint Research Center (Italy) and INAB-RWTH Aachen University (Germany), as well as the Brazilian Ministry for ST&I prepared a recent report of the EU Brazil Sectoral Dialogues Program on niobium. A cooperation agreement was set up with the Brazilian company CBMM, which is the largest producer of niobium globally. Besides CBMM, other niobium producers in Brazil are Niobras (owned by China Molybdenum Co. Ltd), Niobec (a Canadian company), and Taboca (owned by the Peruvian company Minsur).

Brazil is responsible for over 90% of the global production of niobium. Niobium is not the most important metal for the Brazilian economy; more important ones include iron ore, gold, copper, tantalum, and natural graphite. Niobium plays an important role in the steel industry, for example to create high strength-low alloy content steel for pipelines, construction, transportation (automobile industry), and superalloys for aeronautics. It is also a strategic material for superconductors, for example used in the European Large Hadron Collider and for medical imaging diagnosis (MRI). A new development (from a partnership between CBMM and the Japanese Toshiba) is niobium titanium oxides anodes for lithium-ion batteries.

Niobium is not rare, but Brazil operates mines that are relatively large and with a high niobium content. The report “Study of critical materials’ production chains: opportunities and threats of the circular economy"[1] provides overviews of trade flows and end-uses of niobium. Based on MFA data from Europe and the Material Circularity Indicator of the Ellen MacArthur Foundation/Granta, niobium (generic) has a low circularity score of 0.14 (with 0 = not circular and 1 = fully circular) and niobium (steel) of 0.11. There is hence an opportunity to improve the circularity of niobium.

In an analysis of scientific papers and patents, it appears that most innovation takes place at the development of alloys and in the steel sector. Other areas of interest are anodes, cathodes, sensors, electrodes, and catalysts. Most patents are from China, the US, Korea, and Russia. Brazil focuses R&D on extractive metallurgy. There are federal government plans to fund a new research lab for niobium and graphene materials. Also CBMM invests in innovation via partnerships.

CBMM provided access to data to conduct an environmental and social Life Cycle Assessment on niobium. Niobium can already contribute to sustainable development by the creation of low-weight materials, for example in the automotive industry. However, countries that supply raw materials may need partnerships to enhance the sustainability of mining and processing operations. Consumer countries may strongly support and finance good sustainable practices.

Nathan Williams (Minespider, Germany): Blockchain technology to improve transparency in the mining sector

Blockchain is an emerging technology with the potential to improve transparency in the mining sector. The technology allows people to know where a material comes from, and under what conditions it has been produced.

Blockchain could be understood as a database that can be used to make unique digital items. As each item is unique and unchangeable (copies can be identified), the items can store value. Minespider uses this concept to create digital certificates. These certificates can be linked together, gathering information from every supply chain actor, in order to transfer supply-chain information.

With supply-chain traceability, one could start at the mine site, and push data down the supply chain. This was done at the Minsur's tin mine in Peru, where information was tracked downstream to two different end-users. Alternatively, one could start at a downstream user that wishes to discover who operates in their supply chain and what data can be retrieved. This was done with Volkswagen. Information could be traced about carbon emissions, policies, willingness to supply data, and documents that facilitate international trade could be generated. It goes beyond responsible sourcing; this strategy also allows companies to secure their supply, verify their purchases, and have confidence in the data.

Minespider's first approach was to create digital twins of physical material shipments in the blockchains (e.g. 1 ton of metal is represented by "1 ton" of blockchain certificate). The twins are linked via QR codes. To establish this digital twin model and maintain chain of custody, an end-to-end consortium is needed. This effort was not easily scalable, as all participants should be signed up before

[1] http://www.sectordialogues.org/documentos/proyectos/adjuntos/0c2724_Final%20Tecnical%20Report_WEB_ENG.pdf; password circular5

traceability is started. The needs of supply chain participants are furthermore diverse: upstream suppliers are interested in market access, investment, and social license to operate, via provision of data and differentiation of their products. Regulators and downstream companies mainly look for transparency and supply-chain security. Needs of traders in the middle are shifting from the protection of supply-chain information to active participation in sharing information. The needs of upstream suppliers are often overlooked. Scalability of blockchain solutions towards better supply-chain transparency can be increased by demonstrating the value from traceability to producers, even if they participate on their own.

As long as the supply of traceable materials is limited, encouraging the demand for these minerals only leads to the shifting of the problem to other value chains. Therefore, incentives are needed to increase responsible supply. To respond to the need of suppliers to differentiate their products and stand out from the competition, Minespider rebuilt their system to allow for point-to-point traceability. Instead of providing a digital twin of the supply chain, QR codes are generated that represent two-sided certificates linking data from a sender to a receiver. In this way, the chain of custody is not interrupted if one supply-chain actor does not participate in the scheme, as information can still be collected by downstream actors. This system was implemented by a smelter in Rwanda. By scanning a QR code, access was provided to documents that are legally required to import minerals to the EU in compliance with the EU Conflict Minerals Regulation. This information-sharing provides value to both the smelter and the importer, and motivates both parties to participate. As a next step, mines, processors, and traders can be added to the chain, which makes this approach easily expandable.

Thirtha Biswas (CEEW, India): Formalizing the recycling sector to make CRM supplies more sustainable

Thirtha Biswas works for CEEW, a not-for-profit research think tank that focuses on climate change, resource security, and India's long-term climate strategies.

Currently India is going through a helium crisis. Most helium is imported from the US. The US are currently decreasing their exports; hence, Indian industries are looking for alternative sources. However, CRMs still do not receive the necessary attention. Most revenue of mining is earned by bulk resources, such as coal, iron, perhaps aluminium. While moving to a low-carbon economy, jobs and revenues should be transferred from the bulk minerals to strategic minerals used in low-carbon technologies.

In 2016, a criticality assessment framework was developed for India. Criticality is evaluated regarding economic importance (country's objective: manufacturing economy, social needs, energy needs, defense requirements), supply factors (geological availability, recyclability, substitutes availability), geopolitical parameters (economical & political stability of supplier country, policy & regulations, geographical concentration), and environmental aspects. 49 minerals across 16 manufacturing sectors were evaluated for 2015 and 2030. In 2030, the most critical minerals will be phosphate, Sr, Sb, V, Nb, Si, Mo, Ge, potash, light REEs, dolomite, PGMs, Co, and Mn. Potash and phosphate are highly critical for national food security, and India is entirely dependent on import of these minerals. Dolomite is critical due to its use in the iron and steel industry, which is expected to strongly increase. Depleting resources and declining ore grades make India more reliant on import of dolomite as well.

India has a renewed focus on domestic value creation and self-reliance. During the COVID pandemic, the government provided fiscal incentives and support measures to domestic industries. One measure was a Production Linked Incentive scheme to support 10 critical sectors, including steel, and low-carbon technologies (e.g. photovoltaics, EV batteries). However, the focus on production performance does not incentivize manufacturing, as costs of manufacturing are for 45% determined by raw material needs. Fluctuating prices strongly influence this sector.

Recycling is one strategy to decrease India's dependency on import of raw materials. Metals typically recycled from e-waste are Al, Cu, Fe, Co, Li, Au, Ag, Nb, Pd, PT, Se, and light REEs. Except for Al, Cu, Fe, Au, and Ag, India is entirely dependent on import of these metals. In 2019, India generated around 1.02 million ton of e-waste, 12% of global production, making India the 3rd largest generator of e-waste. The bulk of this waste is represented by computer and telecom devices (82%), mostly from the service sector industries. Other sources are large appliances and medical equipment (15%) and small household EEE (3%). Of all the waste, only 2.5% is recycled – mostly (95%) by un-authorized recyclers, i.e. the informal sector.

In 2019, India imported $324m of CRM, in contrast with $59bn of all minerals and metals. Comparing the current imports of CRMs with the metals embedded in the e-waste flows (focusing on computers and small IT devices, assuming a recycling rate of 80%), 44% of the imported CRMs could be obtained from the recycling of existing e-waste flows. Still, even with increased recycling rates, the quantity that can be recovered is a fraction of India's future demand for CRMs.

For some CRM, consumption of recycled CRM is already high – although not necessarily reducing import reliance. India imported in 2019 1t of palladium from the UK. In turn, the UK imports most of their palladium from Belgium, where the recycling company Umicore strongly contributes to the national import/export balance. Another example is selenium, which is recycled from anode mud, a by-product of copper smelting. The majority of selenium imports to India comes from Korea, which is the 5th largest exporter of selenium. Korea does not have copper ores, their copper smelters rely on imported ores. India also imports and refines copper ores, however, does not recover selenium.

Key policy recommendations are:

1) **The strengthening of national policies.** Current recycling targets are based on the collection rate, instead of the recovery rate. As a consequence, recyclers have focused on mechanical separation of e-waste, instead of chemical separation, resulting in low recovery rates. Import of electronic waste increased between 2015 and 2019 by 390%. However, the refining capacity remained constant. Another recommendation is extending the scope of extended producer's responsibility (EPR), incentivizing the take-back of old equipment by OEMs. This will stop waste flowing into the informal sector.
2) **Prepare national inventory to track mineral flows.** In the informal sector, it is not possible to track material flows and recovery rates. Anecdotal evidence suggests that recyclers only recover visible gold (0.18g), silver (0.02 kg), and copper (0.018 tonne) per tonne of printed circuit boards (PCB), which is only a fraction of the total quantity of recoverable metals. The

remaining PCB waste is shredded and exported. The national inventory of mineral flows should be strengthened to understand what minerals can be recovered, current recycling rates, and current capacity utilization (which is low at present). Even though a current act mandates recyclers and dismantlers to maintain records of e-waste for the state and central pollution control boards in India, these reports are infrequent and not standardized, and focus on the input flows, rather than the flows of recovered materials. E-waste flows could be mapped by triangulating information between recyclers, collection centres, and PROs (producers responsibility organizations, which take over the responsibility of the end-of-life of products from OEMs).

3) **Develop robust e-waste supply chains.** Strengths of the informal sector (collection) should be combined with strengths of the formal sector (advanced recycling technologies). Formalization does not have to imply a loss of jobs or revenues. Employees in the informal sector can be incentivized to work in better environmental conditions, with less health risks, and increased job security. Creation of formal jobs can lead to safe recycling practices, higher income generation, and higher levels of employment. Robust supply chains start at the households. Increased awareness and access to collection points can help better waste separation. Here, PRO's and local municipal governments play a role. India can learn from best practices in, for example, Europe.

Dieuwertje Schrijvers (WeLOOP, France): Circularity strategies to secure supply – Results from international collaboration

The presented work is a result of the International Round Table on Materials Criticality (IRTC) – a project funded by EIT RawMaterials (a body of the European Union under the Horizon 2020 program). The project aims to advance research in criticality assessment, foster international exchange, and raise awareness about materials criticality. IRTC now represents an international network of experts from research and industry.

Partners of the IRTC network evaluated the potential of criticality mitigation via increased circularity. 5 industry case studies were analysed, each from the perspective of an industrial focal actor: 1) rhenium in superalloys for turbine blades (from the perspective of a jet engine manufacturer), 2) PGMs in chemical processing catalysts (chemical plant/oil refinery), 3) REEs in permanent magnets for HDDs (magnet manufacturer, e.g. Hitachi Group), 4) various CRMs in consumer electronics (consumer electronics manufacturer, e.g. Apple), and 5) helium as cooling agent in superconducting magnets in MRI machines (hospital).

For each case study, the relevant circularity strategies were identified. Material recycling at the end of life is often considered as the only circularity strategy for CRMs, and indeed this strategy was observed in multiple case studies. Besides end-of-life recycling, in the rhenium case, new scrap recycling was increased when rhenium prices increased ten-fold. Rhenium consumption was further reduced by extending the lifetime of turbine blades via repairs. Product lifetime extension was also achieved in the case study on PGMs, where the catalysts are regenerated and reused. In the case study on consumer electronics, reuse was enabled via the take-back and redistribution of end-of-life Apple devices.

Multiple motivations to implement circularity strategies were distinguished. A multitude of motivations could be relevant in parallel, such as cost savings, reduced exposure to supply insecurity, reduced exposure to price volatility, regulatory constraints, and brand reputation. For example, the rhenium market is very small. A disruption in the market is likely to affect the jet engine manufacturer. Increased recycling decreases their vulnerability to disruptions in this market. At the same time, costs savings could be achieved. In the case of Hitachi Group, recycling was initially motivated by governmental regulation, leading to investments in recycling technologies and infrastructure. Once operational, the recycling strategy was also cost-beneficial. Even though circularity is often mentioned as a solution for the environment, it should also provide a solution for a company in order to take place.

Several circular strategies observed in the case studies take place within the boundaries of one industrial actor, or with close collaboration with other value-chain actors, for example via long-term contracts. Vertical integration appears to be a beneficial condition to enable circularity, as the company keeps a tight control over the material flows. Via retained ownership (e.g. via leasing or product-service-systems), control could be maintained over the material during the use phase, for example, in the rhenium case, by providing the jet engines as a service to the airplane, rather than selling them. Business-to-business relationships could be more favourable for circularity than business-to-consumer relationships. Materials sold to consumers tend to be more dispersed in number and geographically, making collection a bottleneck. B2B-relationships could be mimicked with consumers by making the circularity strategy also profitable for the consumer (e.g. via gift cards in the Apple case).

The potential of circularity to mitigate criticality is discussed. The company that is concerned about the accessibility to CRMs can only mitigate their criticality via a circularity strategy if the raw materials come back to the same company in a closed loop. In other contexts, recycling in a closed loop does not necessarily require materials to go to the same manufacturer (e.g. Hitachi Group), as long as the materials are used in the same application (e.g. hard disk drives). However, if other manufacturers of hard disk drives use recycled rare earth elements from the HDDs produced by Hitachi Group, Hitachi Group does not benefit from decreased supply risks. Therefore, if we talk about circularity in the context of CRMs, it is important to take the perspective of a focal actor – i.e. the industrial actor that is concerned about supply risks.

Discussion

The discussion – live, in the chat, and on the virtual whiteboard – revolved around a variety of issues. It was especially highlighted that a stronger focus on self-reliance is observable world-wide, while securing sources from foreign countries has become a comparably lower priority. Participants agreed that there is a trend towards increased resource nationalism, which changes the global landscape.

Materials of importance

Lithium, nickel, cobalt, and PGMs are mentioned as being especially high on national agendas for exploration. It is added that not only CRMs, but also base metals like copper or iron for

infrastructure will be crucial for the energy transition, with increasing demand and also a high recycling potential.
Countries currently dependent on oil and gas export will need to diversify in the long term. Ideally, developing countries could utilize incomes from fossil fuels to fund exploration in minerals, and make use of the opportunities that come with the competition for CRMs in the energy transition.

Criticality assessments

Criticality is defined from the consumer perspective, considering supply risk and (economic) importance. How do we balance the importance of this criticality with ESG and relations with undeveloped producing countries? What are the best initiatives showing the strengthening on these partnerships? One participant adds that criticality assessments should incorporate a third dimension of environmental and social impact analysis in order to provide guidance on priorities. It is further suggested that it should also be assessed how efficiently the use of the elements in question can contribute to the total material flows, for example for dematerialisation, which is key in the low-carbon economy challenge. In addition to country concentration, corporate concentration should also be measured, as production is governed by companies. It can be higher than country concentration as companies can be active in several countries. Regarding availability, it could be useful to consider ore grade decline over time in relation to its effect on the cut-off market price per country and even globally in the long term.

Challenges to fulfil national CRM demand

Challenges to fulfil national CRM demand include the secure supply of CRMs in both the public and the private sector, lacking capability of the recycling system to keep up with increasing metal demand, and the occurrence of CRMs in radioactive ores, which poses challenges for regulation regarding the environment and health and safety. In general, social and environmental impacts on the one hand and a societal reject of mining on the other hand were named as the number one challenges for some countries to increase domestic mining activities. Also, it is mentioned that, for materials such as tantalum, there is a high variability in supply depending on current markets as well as opacity in artisanal supply chains, combined with little exploration to determine resources.

Required information on CRM

What type of information about CRM supply should become more accessible? Provenance information is of high importance, along with the information wether the material passed through conflict affected or high-risk areas, information about the regulatory framework of the country of origin, as well as documents and data confirming compliance with this framework. Carbon emissions and other environmental impacts are of interest as well. It is important to convince companies to engage in data sharing and also be more open regarding the Life Cycle (Sustainability) performance of their products.
Products need a digital Bill of Materials in order to identify their CRM composition. An example of Government support for data allocation is the Korean Mineral Resource Information System KOMIS.

Blockchain approaches

There is a need for companies and governments for better transparency regarding the origin of metals. The LBMA (London Bullion Market Association) is aiming to make a gold bar registry and is currently evaluating different authentication security features. The IFG (Institute for Forensic Geology) reported that the Swiss refiner Metalor, in collaboration with the Swiss Government, Innosuisse and the University of Lausanne, announced the development of a, 'Geoforensic Passport' for responsibly sourced gold. Its success in gold value chains might indicate that blockchain is currently easier applicable to raw materials of high value. However, there is also an advantage to lower-value materials: there is less incentive to "game the system", and the volumes tend to be higher, which makes fraud more difficult. Areas like carbon emission tracking, import document management, and incident reporting are not dependent on the value of the material tracked. Blockchain technology could be a breakthrough in fulfilling UNRMS needs regarding responsibility and transparency.

Circularity

How can more circular business models be implemented? It is emphasized that many CRMs are highly diluted in applications. For example niobium: due to its major use in steel alloys, recycling can hardly help to support supply. Data on secondary resources are not captured in national databases; an according information system is required. It is suggested to establish an international open online platform which can be accessed by industry members and anyone who has questions, information, or comments to share with others in the world. Since the circular industry is an unavoidable trend, knowing early about new practices, regulations and standards from other parts of the world is crucial to allow for a fast response. Also, the important role of utilizing "waste" materials for sustainable supply is highlighted, such as mining waste, currently unused by-products (e.g. Cd and REEs from phosphate rock), and anthropogenic resources. Furthermore, innovative approaches such as resources as a service must be considered, as adopted by the platinum industry.

Artisanal mining

Many countries with demonstrated potential for mining have limited capacity among mining authorities and ministries. Artisanal miners need help to get organized, implement due diligence capacities and build trust with governmental institutions. Bringing artisanal miners on sustainable pathways could bring high positive impact on their communities on the one hand, and the mineral value chains on the other hand. A number of European bodies already assist developing countries with capacity building, e.g. Denmark, Germany, Netherlands or UK in various countries in Africa. Government aids are a pathway to start with, but finally, companies must implement good governance.

Capacity building

For resource-rich developing countries, the competition for resources among the industrialized nations can be an opportunity. The energy transition could thus offer them a chance for long-term revenues and the establishment of a skilled workforce. The African Mining Vision and the African Mineral Development Center are ways to operationalize local potential; there is a shift in the view of the potential of minor minerals. Nigeria and Angola are examples of countries that try to make this shift towards exploiting minerals. But there are still hurdles to overcome in the development in exploration skills and improvement of training and education in order to build the capacities that will be necessary for achieving long-term development through mineral resources.