How companies improve critical raw materials circularity: IRTC-Business Workshop co-organised with the EU Raw Materials Week

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How companies improve critical raw materials circularity

IRTC-Business Workshop

Co-organised with the EU Raw Materials Week

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Executive summary

The workshop "How companies improve critical raw materials criticality" was co-organized by the International Round Table on Materials Criticality in its current project IRTC-Business. After IRTC had investigated the potential of circular strategy to mitigate criticality of critical raw materials in earlier events, discussions and publications, the workshop aimed at understanding concrete applications of circular strategies, in order to identify their drivers and hurdles. For this, a variety of companies were invited to present their business models.

The workshop started with examples of good practice: renown cases of successful business models that keep critical raw materials in the loop. Speakers from Hitachi Group, Rolls-Royce, Umicore and H.C. Starck Tungsten presented insights on how they recover rare earths, rhenium, platinum group metals, and tungsten. The examples showed that ideally, technical possibilities – such as recovery yields and suitable machinery – meet favourable business conditions, such as markets with limited actors that allow for B2B models or vertical integration, thus optimizing material flows.

The second part investigated drivers and challenges: regarding the economics of rare earths recycling, environmental footprinting of secondary sourcing, data requirements, and collaboration. There are strong drivers for Europe to increase secondary sourcing, which offers benefits by adding to supply, decreasing demand and lowering the environmental footprint of material use. Hurdles are identified in material availability of secondary sources and the competitiveness of recycling processes. Data availability is key to assess impacts and origins of both primary and secondary raw materials.

In the third part, recent and future development regarding secondary CRM sourcing were presented, comprising views of different sectors: consultancy, telecommunication, data science, and battery recycling technology. The relevance of metrics for CRM circularity to measure performance was highlighted, as well as the need to identify risks early on also in sectors beyond the manufacturing industry. Regulation and policy goals were identified as important drivers to aim at expansion of CRM recycling, such as minimum recycling rates for specified raw materials. Regulations

aiming at tracking material contents could be drivers for data sharing in an environment that protects company confidentiality.

The fourth part was about new approaches on circularity for CRMs, comprising speakers from the photovoltaics industry, electromobility, and consumer electronics. Flexible solutions, such as deciding on the fate of a battery depending on its state of health, offer new possibilities to exploit the shorter loops of the circular economy, thus saving material value and lowering environmental footprints. Modular design allows for repair and longevity in B2C markets. High value recovery requirements, such as considering embedded energy and scarcity, are important factors to take circularity to the next level.

The final part of the workshop opened the floor to questions and discussions, which centered around potential instruments and methods to increase circularity, among them design for circularity and new business models, recycled contents, product as a service, or innovative collaborations.

Agenda

11:00-11:10	**Alessandra HOOL**, ESM Foundation, IRTC-Business **Constanze VEEH**, DG GROW, European Commission	Welcome and Introduction
11:10-11:20	**Dumitru FORNEA**, Member of the European Economic and Social Committee	Boosting critical raw materials resilience through secondary sourcing and substitution technologies: a view from organized civil society
11:20-12:00 Good practice examples: what is working?		
	Yasushi HARADA, Hitachi Group	Rare Earths recycling of magnetic hard disk drives
	Andrew CLIFTON, Rolls-Royce	Closed rhenium loops in jet engine turbine blades
	Christian HAGELUEKEN, Umicore	Recovering Platinum Group Metals from chemical processing catalysts
	Julia MEESE-MARKTSCHEFFEL, H.C. Starck Tungsten	Paradigm tungsten processing
12:00-12:40 Challenges		
	Alain ROLLAT, Carester	Recycling of Rare Earths – drivers and hurdles
	Dieuwertje SCHRIJVERS, WeLOOP	Measuring impacts of recycling models
	Mesbah SABUR, Circularise	Using data to improve circularity: what is missing?
	Mario WEIKENKAS, Enterprise Europe Network	Partnering and funding for SMEs in the CRM field
12:40-13:10	**Lunch break**	
13:10-13:50 Reacting to today's challenges, and preparing for tomorrow's: what is next?		
	Arnoud WALRECHT, KPMG	Circular metrics to assess material risks

	Jeroen COX, KPN	Reducing raw material risks: a view from the telecommunication sector
	Nathan WILLIAMS, Minespider	Big data for improving CRM circularity
	Hendy KIM, SungEel Hitech	Battery recycling: recovering the whole range of raw materials
13:50-14:30 New approaches on circularity		
	Leah CHARPENTIER, First Solar	Closing the loop on PV recycling
	Olivier GROUX, Kyburz	Reuse and recycling of traction batteries
	Thea KLEINMAGD, Fairphone	Design for repair in consumer electronics
	Rajarshi Rakesh SAHAI, ACM	Adaptive solutions for electric mobility
14:30-15:00 Panel discussion		
	Previous speakers and **Gian Andrea BLENGINI**, University of Torino **Roderick EGGERT**, Colorado School of Mines **Magnus ERICSSON**, RGM Consulting **Atsufumi HIROHATA**, University of York **René KLEIJN**, Leiden University **Anthony KU**, NICE American Research **Min-Ha LEE**, KITECH **Ajay PATIL**, Paul Scherrer Institute **David PECK**, TU Delft **Carlos Cesar PEITER**, CETEM **Luis TERCERO**, Fraunhofer **Patrick WAEGER**, EMPA	What are prerequisites for companies to improve CRM circularity?

Abbreviations

ACM	Adaptive City Mobility
ATM	Automated Teller Machine – cash dispenser
APT	Ammonium paratungstate
CapEx	Capital expenditures
EEN	Enterprise Europe Network
EMPA	Swiss Federal Laboratories for Materials Science and Technology
EoL	End of life
EV	Electric vehicle
HCST	H.C. Starck Tungsten
HDD	Hard Disk Drive
ICT	Information and communication technology
LCA	Life cycle assessment
LIB	Lithium-ion battery
OMEC	Organisation of Metals/Minerals Exporting Countries
OpEx	Operational expenditures
PCB	Printed Circuit Board
PGM	Platinum group metal
REE	Rare earth element
REPM	Rare earth permanent magnet
TCO	Total cost of ownership
WBSC	World Business Council for Sustainable Development
WC	Tungsten carbide

1 Introduction

Alessandra Hool, as organizer of the workshop, is happy that many speakers and panellists have joined the event. The workshop is co-organized by IRTC-Business, the International Round Table on Materials Criticality, which a is in its second round until the end of 2022. After that, it will enter the third round and continue for another three years, while establishing an annual international criticality conference. After a lot of interesting exchange and academic output of the project on a more circular economy of critical raw materials, today's workshop shall shed light on the industry perspective. It thus features the many interesting examples of critical raw material circularity from industry.

The EU Raw Materials Week is organized by DG GROW from the European Commission. Constanze Veeh indicates that policy makers are frequently not in touch with companies. Therefore, this workshop is a great opportunity to engage with each other. As a policy roundup, Ms. Veeh explains that the EC has published its new industrial strategy, which focusses on ecosystems instead of sectors. This strategy, the EC's regular work on CRMs as well as the foresight study on CRMs[1] emphasize Europe's dependence on critical raw materials. While international collaboration is important, strong supply concentrations of raw materials pose risks and should be counteracted. The European Green Deal Circular Economy Action Plan, at the same time, increases Europe's need for and therefore dependencies on critical raw materials.

Dumitru FORNEA, Member of the European Economic and Social Committee (CCMI), addresses how to boosts critical raw materials resilience through secondary sourcing and substitution technologies, reflecting the view from organized civil society. The European Economic and Social Committee has 329 members and is representing society from a broad range such as employer organisations, mining companies, trade unions, and environmentalists. Civil society, including NGOs, today recognise the crucial role of raw materials supply for a low-carbon future. The Consultative Commission on Industrial Change considers it crucial that society is informed about how supply chains are formed and where raw materials are from. The CCMI is looking forward to hearing about good practice examples of CRM circularity from industries world-wide.

2 Good practice examples: what is working?

2.1 Rare Earths recycling of magnetic hard disk drives

Yasushi HARADA, Hitachi Group

5 years ago, the Hitachi Group formulated its Environmental Vision. This vision defines the goals in environmental business practice as well as long-term ambitions for environmental innovation. The vision aims for three goals: a resource efficient society, a low-carbon society and a society harmonized with nature.

One motivation for recycling is resource scarcity. For the majority of resources, the reserves have declined in the past 10 years. Hitachi, like other manufacturers in Japan, is impacted by stagnated imports of raw materials.

To achieve a circular use of resources, Hitachi's Product Recycling Service Center has been established. After use, products are collected in these recycling centers, then go to intermediate processors and finally recyclable materials go back to metal smelters. Hitachi's product recycling service center is a collaboration between Hitachi's business and services division and 16 affiliates, which are together recycling 100 different products. The recycling center is certified

[1] https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

by the Ministry of Environment of Japan under the National Permit System for industrial waste. This system is applied throughout Japan and includes regulations to standardize security management and recycling procedures.

Used products such as servers, PCs and HDDs are disassembled into parts, in many cases by hand. The constituting materials are separated. This process has handled in total about 500 t of products in 5 years. HDDs account for 10 t (20,000 drives). The examples of cash dispenser (ATM) and hard disk drive (HDD) recycling are being discussed. The number of ATMs collected by Hitachi is varying, with recent years showing a growing trend. Since ATMs are IT electronics that demand high security, trusted information sharing between the manufacturer (Hitachi Channel Solutions, Corp.) and the disassembler (Hitachi Industrial Equipment Nakajo Engineering, Nakajo EG) is of high importance.[2] About 2000 ATMs per year are being delivered to Nakajo EG, collected both via Hitachi's National Permit System channels as well as independently by Hitachi Channel Solutions. During disassembly, the ATM is broken down to single-material components as much as possible. There are about 20 part types and until now, 7,000 parts have been reused in maintenance. ATMs are made of mainly metal, but also circuit boards, cables, batteries, HDDs, plastics and glass. 99.6% by weight can be recovered.

A HDD is composed of several components and materials. The voice coil motor is of interest as it contains rare earth elements (REEs). Manual disassembly can only process 10-12 HDDs per hour. Therefore, Hitachi developed an automatic HDD disassembler between 2009-2011 with support of a government grant. The machine can process 140 HDDs per hour. In six years, it has extracted 26 t magnets, fulfilling 10% of Hitachi's need for magnets. Moreover, significant CO_2 emissions are avoided.

Switching to a circular flow reduces the quantity of disposed materials and opens new ways for adding value, such as magnet reuse and material recycling. This contributes to a better coexistence of humans and nature. Hitachi commenced the scheme purely as a way to reduce environmental impacts, but can now produce recycled materials at a lower cost due to automation. Therefore, the scheme is economically viable and can be continued in the future.

2.2 Closed rhenium loops in jet engine turbine blades

Andrew CLIFTON, Rolls-Royce

Andrew Clifton presents an overview of how the aerospace industry deals with rhenium recycling. Rolls-Royce is active in a sector that is constrained by very high requirements for safety and performance. Therefore, the manufactured products have very particular material requirements, which is illustrated here at the example of turbine alloys. Turbines experience very high temperatures and forces, which they can withstand better with alloying additions. Various alloying elements have been used in nickel superalloys, including rhenium. This started with the first generation of single-crystal alloy designs.

Given the high performance requirements, substitution is very challenging. The only example of successful substitution is the replacement of ruthenium, which took about 10 years. Instead, Rolls-Royce aims to retain the materials in closed loop supply chains using a variety of options for material flow management, chiefly the Revert programme. In this programme, wastes are returned to the alloy supplier for reprocessing in aerospace-grade material. In return, Rolls-Royce receives clean alloys at a discounted rate. The discount is greater than the scrap value of the waste on the open market. This is economically beneficial for both parties.

The recycling covers two waste flows: manufacturing waste and end-of-life (EoL) products. Manufacturing waste includes turnings or chips from machining, runners from investment casting of turbine blades. All of these wastes are collected as a single alloy flow. Rolls-Royce also applies more complex processes to recover rhenium-bearing alloys

[2] In former times, Hitachi manufactured ATMs and similar equipment in Tainai City, Niigata. Nakajo EG is the local successor of this legacy and still retains engineers with in-depth structural knowledge of ATMs.

from grinding sludge and blast media. These significant reclamation efforts are driven by both the market value and the strategic value.

For EoL recycling, Rolls-Royce has a circular business model with service contracts for civil aerospace and total care. All assets come with a fixed fee per flying hour to cover maintenance. This forces Rolls-Royce to think about life cycle costs and life cycle extension, while also giving access to replaced parts. These parts can be reused, repaired, or reprocessed.

The net result is that 50% by weight of a Rolls-Royce engine is made of closed-loop recycled alloy. The other half is recycled at a lower quality. For example, titanium can be contaminated and has a lower margin for purification. This demonstrates how Rolls-Royce manages materials in a more circular way.

2.3 Recovering Platinum Group Metals from chemical processing catalysts

Christian HAGELUEKEN, Umicore

Christian Hagelüken presents a good practice example of closing the loop of platinum group metals (PGMs). Various combinations of PGMs are used in process catalysts, both in oil refining and in catalytic chemical syntheses. The annual consumption of PGMs in a specific application can range from tens to hundreds of kilograms. PGMs are not only essential in process catalysts, but also for automotive catalysts, H2-electrolysis, electronics, fuel cells, etc. Since PGMs have high market prices and their content in catalysts is relatively high, they have significant influence on the catalyst costs. Combined with the high price volatility, this urges industrial users to minimize the life cycle losses. For decades, PGM catalysts are integrated in circular strategies.

In these strategies, a distinction is made between suppliers and users. If the industrial user is the focal actor in the life cycle, usually all other processes are contracted as a service. This B2B business model focuses on product performance and services. In the first use, the user pays a split price for the PGMs and the catalyst manufacturing. From the moment of shipping onwards, the user owns the PGMs. The user maintains contracts with service providers for regeneration to extend the lifetime and for recycling of spent catalysts. At the EoL, PGMs are recovered and treated under a 'toll refining' service based on the analytically measured PGM content. The recovered PGMs are used to produce a new catalyst, hence not subject to market price volatility. Only small losses need to be compensated with virgin PGM. Full transparency is achieved because a limited number of professional actors is involved and the catalyst remains at a fixed location during the use phase.

In the example of a Rh-Oxo catalyst, Umicore supplies the catalyst (containing e.g. 25 kg of rhodium) to a chemical plant. After ca. 6 months, it is exchanged and returned to Umicore, where the exact Rh content of the spent catalyst is determined. The recycling is done against a service fee, and the recovered rhodium is credited to the customer's account. Assuming a life cycle loss of 10% rhodium, the user saves $6-20 million each year, depending on the market price. Therefore, the user benefits from better economics and lower price risks, reduced dependence on primary PGM suppliers and significant CO_2 footprint reduction.

PGM process catalysts are a potential role model for circular metal businesses. The drivers are high product values, vulnerability to price fluctuations and PGM supply risks. The success is based on a B2B business model which inherently rewards high performance products and services along the lifecycle. The professional and long-term interaction between industrial actors secures full transparency.

2.4 Circular economy-paradigm tungsten processing

Julia MEESE-MARKTSCHEFFEL, H.C. Starck Tungsten

Julia Meese-Marktscheffel is responsible for global technology and innovation at H.C. Starck Tungsten Powders (HCST). She explains HCST's approach to the recycling of tungsten. HCST has its headquarters in Goslar, Germany, where tungsten chemicals, powders and carbides are produced. Other production sites are in Canada and Ganzhou, China. HCST is part of Masan, which owns the largest tungsten mine outside China, in Vietnam.

In Goslar, the main product is tungsten carbide (WC). WC powder has a high melting point. To increase its toughness, customers add 5-20% metallic binder, often cobalt, to generate a so-called hard metal. The properties of this material are determined by the grain size of WC nano grains, ranging from <0.2 µm up to 10 µm. For recycling, two approaches are available. In direct physical recycling ('Zinc reclaim'), the hard metal is decomposed into a Co and WC phase, which can then be reused. This approach has low processing costs, but it needs clean sorted scrap because all impurities in the waste stay in the material. The second approach, applied in Goslar, is holistic chemical recycling. The hard metal is decomposed to single elements, and all types of scrap can be processed.

HCST pursues a secure and stable material supply. Therefore a broad range of wastes can be recycled at Goslar, with about 90 years of experience in W recycling. The scraps usually contain 60-90% W, next to other valuable metals like Co, Ni, Cu, Ta, V, and Cr.

Analysis of the 100-kt global W demand reveals that 60% is used in hard metals, and from this 25% is applied in automotive and 23% in mining and construction. These two application sectors are in the tool industry, creating good recycling opportunities. Hard scraps arise in milling, drilling, cutting, and shaping of metal parts. Soft scraps often contain organic oily components, e.g. cooling, lubricants or cellulose as filter aid.

For soft scraps, the recycling process starts with roasting. Both scrap types then go to an alkaline smelt to oxidize WC to sodium tungstate. The melting cake is then crushed, grinded and dissolved in water. A series of hydrometallurgical processes remove impurities, to yield clean, white ammonium paratungstate (APT). APT acts as a material platform and can be traded on a global market. APT can be converted to WC through calcination, reduction and carburization. The physical characteristics are controlled by the furnace technology.

To conclude, 25-30% of the total W demand is covered by recycling. For hard metal tools and heavy metal parts, the recycling rates are 50-75%. Recycling can still be increased in energy, lighting and chemical applications. HCST combines their growing recycling activities with certified procurement to ensure a safe, sustainable and competitive raw material supply. With Masan as the new owner, new horizons for recycling beyond tungsten open up. New technologies are developed to recycle Co-Ta-W sludges and black masses from lithium batteries. A single plant setup would provide economies of scale and would benefit both HCST and the environment.

3 Challenges

3.1 Recycling of Rare Earths – drivers and hurdles

Alain ROLLAT, Carester

Carester was created in 2019 by former Rhodia/Solvay engineers. Carester specializes in technical services to the rare earth industry, digitization of the REE solvent extraction process, and the recycling of EoL rare earth permanent magnets (REPMs). For the latter activity, a new company was established in 2021: CAREMAG.

There are two drivers for Carester to engage in magnet recycling. The first is the necessity for Europe, with a demand of over 100 kt REPMs per year. Secondly, Carester's expertise in REE separation is essential for magnet recycling.

Three potential hurdles for REPM recycling are investigated: the availability of waste materials, the competitiveness and sustainability of the process, and the existence of a long-term market for recycling products. These hurdles are elaborated below.

Carester and ADEME studied the market of EoL REPMs. They were surprised to find that in 2020, already 3400 t Nd could be collected. In 2040, this could increase to 13 kt Nd and 1.3 kt Dy. After proving this 'deposit', the study distinguished between resources and economically recoverable reserves. A large part of EoL magnets do not reach recycling companies, therefore the EU must prohibit the export of EoL products containing REPMs. The study calculated the optimal level of dismantling for each application type. With a higher magnet content, recovery is cheaper but the dismantling is more expensive.

Carester's recycling process consists of three steps, starting with EoL magnet treatment in a pyro-hydrometallurgical process with improved iron removal and reduced energy consumption. The second step is boron extraction and purification. The third step is REE separation, using solvent extraction via the nitrate route. Compared to the traditional chloride route, the advantages are the absence of liquid effluent and the lower OpEx.

The market for REPMs is large and growing. In 2028, the demand for REPMs in only electric vehicle (EV) motors and wind turbines is forecasted to be 90 kt. The forecasted capacity of CAREMAG is 1 kt per year, so no issues are expected on the demand side. The CAREMAG project plant has a total cost until start-up of €56 million, of which €15 million are covered by a French state subsidy. The plant will be located in the southwest of France, creates 70 jobs, and is expected to start production in July 2024.

3.2 Environmental benefits of CRM recycling

1:42 Dieuwertje SCHRIJVERS, WeLOOP

WeLOOP is a start-up from France, specialized in life cycle assessment (LCA) and criticality assessments for companies. Dieuwertje Schrijvers discusses the environmental benefits of CRM recycling and the factors to account for. Circularity is claimed to contribute to reduced supply risks and to lower environmental impacts. However, the environmental benefits of circularity should not be taken for granted.

This thesis is illustrated with the case of REE recycling from fluorescent lamps, practiced by Solvay during 2013-2016. From collected fluorescent lamps, Solvay extracted REEs, producing new phosphors for use in new lamps.

LCA is a holistic approach that looks at the complete life cycle of products and a broad range of environmental impacts. Many CRMs are critical because they are produced as by-products of other metals. This implies that their supply depends on the demand for the host mineral. This linking has consequences for the environmental assessment of those CRMs.

By-products are generally considered accountable for only a small share of environmental impacts from the value chain. Based on the economic value of co-products, the impacts of a process can be allocated. In the example of REE co-mining with iron ore, only 20% is allocated to REE concentrates. In this approach, the environmental footprint of REEs could be very low. Recycling is also a process with multiple co-products. In the case of REE recycling from phosphors, REEs are a by-product of fluorescent lamps.

Besides, supply risks in the primary life cycle of a product pose a risk for the recycled material. This can be illustrated with the case of yttrium oxide recovery from fluorescent lamps. For most environmental impacts, the recycled yttrium has a lower impact than the primary raw material. An exception is the higher human health impact, due to the toxic mercury in lamps. This toxicity incentivized alternative lighting technologies, thereby limiting this REE recycling route.

In LCA, it is important to know what is replaced by a recycled material. For example, recycled glass substitutes primary glass. This does not always hold true for REEs, considering that primary REEs are by-products. To analyse this effect, we have to identify which REEs are determining coproducts, i.e. which REEs are a limiting factor of the production volume of mines. When looking at REE concentrations in ores from various mines, only Nd, Dy and Y were identified as determining products, and someother REEs are produced in surplus. Because of this imbalance, recycling of many REEs will not lower the mine output. For a few REEs, e.g. Tb and Eu, increased recycling may not avoid primary mining, but may enable increased use of the materials in certain applications, such as in wind turbines or fluorescent lamps. The environmental performance of the recycling activity is strongly dependent on these market situations of the recycled REEs. Such factors must therefore be considered before assuming that a recycling process is environmentally beneficial.

3.3 Using data to improve circularity: what is missing?

Mesbah SABUR, Circularise

Mesbah Sabur is one of the founders of Circularise, a start-up in the field of supply chain transparency. During his graduation, he witnessed the recycling of screens and observed that the recycling company had no information about the products they were dismantling, so they would use hand tools to take the screen apart. The company was required by law to separate hazardous materials, e.g. additives and flame retardants. Some screens don't contain any of these materials, but still need to be dismantled if it is unknown. The problem is that the information is not transferred through the supply chain. In a pilot, this company was provided with the right data. This made the recycling 3-4 times faster.

Circularise strongly believes that data sharing in supply chains is one of the cornerstones of a circular economy. For that, we need an information platform to facilitate data sharing about raw materials, parts, products and recycled materials. At the moment, Circularise primarily works with plastics and chemical companies that are pursuing a sustainable portfolio and investing billions in sustainable alternatives for their primary materials. These efforts remain unseen if the information about their sources is not shared, while there is a strong pressure from regulators and consumers.

Tracing currently proceeds through e-mails and spreadsheets, yet this is very labour-intensive and only affordable for large multinationals. Circularise proposes to create a digital twin for each product, representing its composition by weight. Mass balancing allows companies to report on all their inputs and outputs, whilst tracking the origin of materials. Various other datapoints can be added, e.g. the production site and LCA data. The platform allows anyone to retrieve or upload data regarding the digital product twins. These digital products can be exchanged over the ledger.

The challenge is to scale up the concept, such that it can be used throughout global supply chains. To solve the conflict between confidentiality and a scalable, open infrastructure, Circularise uses 'zero knowledge proofs'. This new technology was first considered impossible, but it allows to make statements on a public ledger, without having to share any sensitive data. A mathematical proof guarantees that the information is correct, while the information itself remains undisclosed. This allows to safely use a public blockchain.

Large-scale sharing requires an open infrastructure. While Circularise's protocol is shared, different software clients can be chosen by each participant. In this way, suppliers and customers from all industries can be connected.

3.4 Partnering and funding for SMEs in the CRM field

Mario WEIKENKAS, Enterprise Europe Network

The Enterprise Europe Network (EEN) is the world's largest support network for SMEs with international ambitions. The program is funded by DG GROW. Since 2008, the EEN has helped SMEs to grow internationally. The decentralised network consists of 3000 experts in 600 organizations in 60 countries. This structure enables SMEs to connect with other SMEs, universities and large companies. EEN combines international business expertise with local knowledge. Thanks to the local experts, EEN provides access to local ecosystems.

EEN's services are grouped in three pillars: international partnerships, advisory support, and innovation support. The pillar of international partnerships stimulates knowledge transfer, by offering a partnership database where universities and companies can create a profile describing their technology. In addition, many-to-many transfers take place during brokerage events and company missions.

During the new contract phase that EEN is about to enter, the focus on sustainability is even higher than before. All services are centred on sustainability, digitalization, and resilience. In the EU Circular Economy Action Plan, EEN also came in place, as the network is trying to support SMEs in this framework. The network is organized in 17 key sectors, in line with the industrial ecosystem. One sector group is materials, in which 26 members are organized and try to do pursue technology transfer, find business partners, and build consortia for EU-funded projects. Also, over 400 materials-related profiles exist in the publicly accessible EEN database. 150 profiles are technology partner searches.

To summarize, EEN builds bridges between EU programmes and connects SMEs to regional ecosystems along the material value chain, with the help of regionally-based EEN partners. EEN also offers access to sector groups according to the EU industrial ecosystem.

4 Reacting to today's challenges, and preparing for tomorrow's: what is next?

4.1 Circular metrics to assess material risks

Arnoud WALRECHT, KPMG

Mr Walrecht aims to provide a briefing on latest developments in metrics and standardization. Measuring is essential for management. In boardrooms, the awareness about sustainability and circular economy is lagging behind. Policy makers and companies focus mostly on carbon emissions, while resource scarcity is underexposed. Yet, a circular economy contributes to achieving net zero emissions. Companies should think about how circular they are, and how to prove it transparently.

The global material flows are 91% linear, according to this year's circularity gap report. This number indicates a huge improvement potential. For example, the energy sector could face a waste problem in the future, according to a recent KPMG report. KPMG argues that the geopolitical aspects of raw materials should be regulated more. Inspired by OPEC, they pledge for coordination by OMEC, an organization of metal exporting countries.

Multinationals agree on the need for uniform metrics for circularity. These metrics provide insight in the risks in the value chain and in where to steer for improvement. Besides, they are useful for external reporting. It is expected that, in 5 years from now, annual reports should include statements on critical raw materials. European businesses call for more standardized product circularity definitions because a common language is missing.

2 years ago, the WBCSD launched a circular transition indicator framework. Now, the first companies are being audited. The business-driven framework helps companies to assess their level of circularity and consists of three modules. The core module, 'close the loop', indicates the circular inflow and outflow, and water and renewable energy consumption, all in percentages. The second module covers the percentage of critical materials. The actual recovery is important, as it depends on both materials and design. The third module links to financial indicators, e.g. circular material productivity. Version 3 and 4 will include metrics for product longevity or lifetime extension. This is one of the hardest circular economy components to translate to universal metrics.

The approach is value-chain agnostic; it can be applied by retailers, OEMs and suppliers. Moreover, the calculation can be done on the level of companies, business units, and products. The basic calculation method is simple, open and transparent. The reporting shows how outcomes can be influenced, either through procurement, design, or return schemes. This way, the company gains control. KPMG has listed the key elements for making the investment case for circular metrics.

4.2 Reducing raw material risks: a view from the telecommunication sector

Jeroen COX, KPN

Jeroen Cox is in the lead for circularity and net zero strategies at KPN. KPN started to explore the circular economy in 2017, leading to awareness of critical raw materials. Although KPN is a service company, it faces the threat of material shortages and is aware of the impacts of telecommunication materials. KPN has conducted several studies together with Industrial Ecology students.

This exploration started at the environmental impacts, then shifting to the impacts of future technology, upstream and downstream impacts, circular strategies, and how to collaborate with upstream suppliers. Next in line is an assessment of criticality and social impacts. Using the EU definition, most of KPN's CRMs are in electronics and come from China. KPN had already engaged with some commodity material suppliers, e.g. to change the plastic casing or to make product passports. These suppliers are willing to engage in the discussion and were approached again to investigate the origin of PCBs. This allows to think about material alternatives.

To make the complex matter more understandable, for four selected products the number of CRMs was visualised. For example, a blade server contains 31 CRMS. The material impacts of future technologies were investigated based on four trends identified in KPN's technology book: 5G, edge computing, photonics, and quantum computing. These technologies use 42 CRMs, indicating that the future equipment is more complex, a trend that is seen in many sectors. Under a full technology rollout scenario, the demand for 14 CRMs exceeds the current annual supply.

For the example case of server motherboards, possible circular strategies were compared. The reduction of CRM content is possible for tantalum. 10 CRMs could be substituted, although some substitutes are also CRMs. There is some room to extend the service life of the server. Recycling is the final option, and is most viable for valuable PGMs.

The implementation follows a holistic approach, trying to influence and train various actors within the company. Strategies are discussed with suppliers, e.g. for stockpiling or software solutions instead of hardware swaps. KPN stimulates knowledge transfers with suppliers, with universities, in online courses and through standardization organizations.

4.3 Big data for improving CRM circularity

Nathan WILLIAMS, Minespider

Minespider is a blockchain for digital material passports and supply chain tracking.

Nathan Williams stresses that incentives are essential to enable data sharing to improve CRM circularity. There are many reasons for the currently low circularity of CRMs. We must know the barriers from the company perspective in order to solve it. Suppliers are very specialized, with limited vertical integration in CRM supply chains. Actors in each supply chain stage are concerned about their sales, while regarding recycling as an externality. Many CRMs are by-products, meaning their production is not the core business of miners, and there is no economic reason to share data. Often, it is easier to build new products than to recycle old ones, both process-wise and for branding. Decision-makers prefer a cheaper design over a product with better recyclability, because they are accountable for their own business and their shareholders. Moreover, recycling is hindered by data gaps, because products with an unknown composition are very difficult to recycle.

Some of these issues can be solved by Big Data, or in this case *distributed data*. The data are owned by different companies and players, so these diverse data sources must be connected to get the required data. Blockchain can help to gather and link supply chain data, but only works if it benefits the data providers. Suppliers must be motivated using a balanced carrot-and-stick approach. The first movers in becoming transparent have the disadvantage of being scrutinized most. To avoid this punishment, it is important to set realistic expectations about e.g. the benchmark for carbon emissions. Can the costs of compliance be reduced to make it more attractive for companies? Customers are willing to pay a higher price for compliant products. Other benefits could be access to a larger market.

Earlier projects show the complexity of traceability. An end-to-end consortium does not scale well, because supply chain actors have different needs. Therefore, upstream suppliers need to see the value of participating on their own. It was found that suppliers want to decommoditize, tell their story and stand out from the competition. They also want insight in how many people are seeing their data, as this metadata helps to tailor their business and be more responsible. Starting with point-to-point traceability creates a market for transparent materials from the beginning.

There is a bias in the market that EU companies are more willing to share data. This is because of the EU REACH regulation, which forced the creation of departments to collect and share data. Therefore, similar legislation for CRMs will be painful in the beginning, but will pay off once the investments are made.

4.4 Battery recycling: recovering the whole range of raw materials

Hendy KIM, SungEel Hitech

Hendy Kim presents how SungEel Hitech recycles Li-ion batteries (LIBs). SungEel Hitech has been recycling since its foundation in 2000. The company is located in Gunsan, South Korea and expects a revenue for this year of €100 million. LIB recycling started in 2008, with the construction of the first pretreatment plant. In 2011, a hydrometallurgical plant was opened, which could recover an increasing number of metals. Along with the popularity of battery electric vehicles, closing the loop of LIBs is becoming a hot topic. The recycling market is projected to grow to $18 billion in 2030.

The battery cathode contains cobalt, nickel, lithium, manganese and aluminium. These elements are mainly recovered because they are expensive. However, the recycling of anode materials is still under investigation. Recycling processes can be categorized as pyrometallurgical, hydrometallurgical or as direct recycling. Each approach starts with the disassembly of EoL batteries. The processes that follow depend on the route. The battery pack needs to be discharged first. Then, the case can be opened, and the cells are taken out.

Currently, some steps are manual, but robots can take out the modules. The cells can have a cylindrical, prismatic or pouch shape. The reasons for using manual labour are the limited quantity of EoL batteries and the multitude of different battery pack designs.

For pyrometallurgy, the disassembled cells are directly put into in a smelting furnace. This yields Ni, Co and Cu alloys, while Li and Mn exit as slag. The OpEx are low but the CapEx are high, requiring large scales. Hydrometallurgy needs further pre-treatment to make battery powders: discharge mechanical shredding, crushing, and sieving. The powders are dissolved in sulphuric acid, then the metals (Co, Ni, Li, Mn) are separated in several stages of solvent extraction. The CapEx and energy consumption are low, but wastewater treatment is needed. Direct recycling aims to reuse the cathode materials by activating the lithium. The process is cheap and consumes even less energy. Still it has many limitations, such as requiring a single cathode type. This approach is thus not yet operated commercially.

Umicore recycles LIBs using pyrometallurgy, while SungEel Hitech and Chinese companies apply hydrometallurgy. Many new companies are emerging in the field. OEMs like Tesla and VW are also starting their own recycling activities. Recycling can reduce CO_2-emissions by 70% compared to mining.

SungEel's process can recover six major elements as sulphates: Co, Cu, Ni, Mn, Li, and Al. These are supplied to cathode material manufacturers. Currently, SungEel operates 6 pretreatment plants and 2 hydrometallurgy centers. By 2025, this will be expanded to 12 and 3 plants, respectively. As a result, 18 kt metal will be produced annually. The vision is to grow further towards $1 billion sales by 2030.

5 New approaches on circularity

5.1 Closing the loop on PV recycling

Leah CHARPENTIER, First Solar

Leah Charpentier points to a research article that projected the PV development needed to meet the Paris climate targets. The article finds that these targets cannot be met with current PV technologies, because industry growth is limited by the weight of debt. This illustrates the scaling challenge and complexity related to CRMs and recycling.

Material scientists around the world investigate new, more efficient PV technologies, often combining various CRMs in thin layers. These developments urge to rethink recycling. Current PV recycling is focussed on glass and aluminium, representing the largest mass but not the largest value. To recover the valuable and critical elements, a lot of work still needs to be done. One challenge is the long lifespan of PV panels, which means that investments will only be used after ten years. In 2050, the recoverable value from PVs is likely to exceed $15 billion, especially with increasing CRM prices.

Contrary to other PV manufacturers, First Solar has invested in recycling. The company has always pursued closed loops, partly because of the choice for thin-film technology, based on the by-product metals cadmium and tellurium. First Solar has a very lean manufacturing process, where design and production are in close contact. Product design always accounts for recycling, the ease of production and the CO_2 emissions. LCA shows that thin-film production has a six times lower footprint than silicon manufacturing. Silicon cell production is labour, energy and material intensive, whereas thin film production takes place in one factory. Besides, the degradation of thin-film panels is lower during the use phase.

First Solar has a recycling scheme since 2005, one year before the company went public. Every new factory has its own in-house recycling infrastructure. Since the start, about 200 kt have been recycled, mostly production scrap and warranty returns. The largest volumes of regular EoL are thus yet to come. The process is mostly automatized, with the exception of waste module handling. The process has two branches, one to recover CdTe and one for glass and laminate material. The process recovers 90% of semiconductor materials and 90% of glass. CdTe is most valuable, and can be reused up to forty times. The glass is reused in glass fibre or bottles, but methods for closing the loop are investigated.

In a market with strong price competition, regulators need to stimulate PV recycling actively. Regulators could add recycling requirements to Ecodesign or Ecolabel standards, and reward recycling in public procurement tenders. These measures need to counterbalance the costs of reverse logistics and recovery versus the low costs of Chinese raw materials. Even though the current volumes of EoL PV are low, recycling must be discussed as soon as possible.

5.2 Reuse and recycling of traction batteries

Olivier GROUX, Kyburz

Kyburz manufactures a range of electric vehicles: sports, personal, delivery, and autonomous vehicles. These vehicles are designed for a first, second and third life and for recycling. The Swiss company has 180 employees.

Kyburz introduces second-life vehicles, a concept which refurbishes returned vehicles. 70% of the old vehicles can be reused, 21% are disassembled to usable parts, and 9% is waste. Returned batteries are categorized based on their state of health. Depending on their state, they have a second life in vehicles, a third life as energy storage, or they are recycled. Most batteries are in a very good condition after 7-8 years, so only 1% goes to recycling. The third life options are a range of portable and stationary storage applications.

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Kyburz has invested in recycling to avoid losing raw materials. The recycling process is direct and chemical free, and recovers over 91% materials in pure form. Conventional recycling uses pyrometallurgy, which is energy and emission intensive and recovers only 40-60%. The hydrometallurgical route uses shredders and solvents and has a high recovery rate. Kyburz takes a different approach, consisting of three steps: storage and preparation, mechanical treatment, and water-based separation and purification. To preserve the battery morphology, the electrode pack is removed from its housing and the anode and cathode are separated. Then the binders of both electrodes are dissolved in water to yield pure copper, graphite, aluminium and lithium salt. Only the electrolyte is not recycled. The recycling equipment is able to recycle batteries from 3000 vehicles per year.

Together with EMPA, the quality of recovered material is analysed to find out if it can be used directly in new batteries. Also, the aim is to automatize the water-based separation step. This way, Kyburz can fully close the loop of their batteries.

5.3 Design for repair in consumer electronics

Thea KLEINMAGD, Fairphone

Thea Kleinmagd explains Fairphone's approach to repair, and how modular design enables circularity. Fairphone started as an awareness campaign on conflict minerals in 2013. The company aims to change the system from within. Faiphone's mission is to create awareness on the issues in the electronics supply chain, and to show that a different approach is possible. This should motivate all other actors in the industry to change for the better.

The impact of smartphones matters. In 2040, ICT is projected to cause up to 15% of the global carbon footprint. An increasing share of this is due to smartphones. Each year, 1.4 billion phones are sold, which last only 2-3 years and only 15% are reused or recycled. E-waste has become the fastest growing waste stream. When we don't keep the materials in the loop, new materials have to be mined. Fairphone's research shows that smartphone recycling is not the ideal solution, because only 30% of materials can be recovered, while most critical raw materials are lost. Instead, the key to environmental impact reduction is lifespan extension.

The lifetime of most smartphones is limited by the durability of standardized components and batteries, software support, promotion of buying new models, and access to cost-effective repair options. Fairphone's approach to longevity focusses on repairability through a long-lasting design, a 5-year manufacturer warranty, and long-term software support. The phone is modular (allowing for repair and upgrades), reliable, easy to diagnose and update, and easy to take back (as a whole or as parts). Functional components of the phone can be replaced with a screwdriver. Fairphone offers several take-back services: repair during the warranty period as well as outside of warranty, module take-back for reuse in phone repairs, and buy-back for any phone type.

For the review of the Ecodesign Directive, Fairphone has several suggestions. The directive should focus on making repairs affordable and accessible for everyone. Manufacturers should be obliged to provide free repair information and should have spare parts and prices available from the moment a new model enters the market. Also, software should not be a means to render a phone obsolete, and the user should be in control of their software and updates.

5.4 Adaptive solutions for electric mobility

Rajarshi Rakesh SAHAI, Adaptive City Mobility GmbH

Rajarshi Sahai is Chief Business & Strategy Officer at Adaptive City Mobility (ACM). ACM started in 2013 as a research project on electric taxis. The objective has evolved over time to offering shared electric mobility across the world in a resource-efficient way.

Three megatrends are coinciding: urbanization, the demand for mobility as a service, and the search for climate-friendly solutions. In 2050, the electric city vehicle fleet is expected to exceed 300 million cars, largely concentrated in the largest cities. Most people world-wide live in emerging-markets cities with a limited electricity grid and have high constraints on affordability.

The solution provided by ACM is a safe car with simple construction that can be charged on the regular grid and up to 11 kW chargers. It takes the middle road between SUVs and electric tuktuks. The low-voltage range-extender batteries (in addition to a small fixed battery of 16kW) can be swapped and used in other applications like renewables storage. The vehicle has space for 5 people and 400l of luggage or 2 people and 1450l cargo. By adding cargo transport as a use case, the cash flow per car increases. To enable sharing, ACM uses a B2B pooling platform. Various digital services are offered, such as advertisements on the car and digital usage-based insurance.

The total cost of ownership (TCO) development is key to affordability e.g. in South America, the TCO of shared mobility cars has doubled due to rising fuel prices and labour costs, justifying the use of EVs that have significantly lesser operating costs. ACM's EVs can save CO_2 emissions thanks to the light-weight design, higher utilization from dual use, smaller vehicle fleet, and a second life for batteries. The business model is based on recurring revenues, thus enforcing repairability and longevity. ACM aims to create a new vehicle segment and therefore welcomes competitors that help to expand the market.

Immediately after the concept launch this year, a strong demand emerged. Agreements for over 250.000 vehicles have been signed, media outlets worldwide reported on the concept and the ACM car was often cited as among the top-5 car concepts at IAA Mobility 2021. This illustrates the need for a sensible EV solution.

6 Q&A

The audience had the opportunity to ask questions to the speakers in a Slido tool during the event. The questions were answered by the speakers after the event.

I wonder what regulatory barriers exist for EU member states to offer contracts for circular public sector procurement? 10-15% of EU spend is Government spending.

Constanze Veeh: The Commission has been addressing the environmental dimension of public procurement in its work on Green Public Procurement, and has released criteria for different procurement areas that encourage public bodies to take a holistic view of their purchasing. These often also address circularity. In 2017, it published a brochure on public procurement for a circular economy.[3] If EU regulation applies to specific sectors, product groups or products, this would however apply also to any public procurement in these areas (e.g. REACH, waste legislation, etc).

Arnoud Walrecht: In theory there are not so many barriers, except fair competition and general criteria to adhere to. Experience learns that experienced sourcing and procurement professionals are rather scarce for government contracting authorities. That is also reflected in GPP or Green Public Procurement. However, there are very interesting good practices across the EU, also on integrating circular economy in (large) public spend.

Mr. Harada, I wonder if Hitachi Group has explored circular product life extension strategies? Their focus seems to be solely on recycling?

Yasushi Harada: Hitachi is providing not only products but also services with the products of health monitoring and life extension. For example, Hitachi monitors the products in operation, foresees the time of their failure and renews the suspicious parts in advance.

Mr. Harada, once magnets are recovered from HDDs, what technology is used to make a new magnet?

[3] https://ec.europa.eu/environment/gpp/pdf/cp_european_commission_brochure_en.pdf

Yasushi Harada: Hitachi is sending back the collection of used resources to Hitachi Metals, Ltd. Then, rare earth is extracted from them by the technology of Hitachi Metals to be reused for magnets.

Mr. Clifton, I am aware that aerospace employs extensive remanufacturing strategies. To what extent does that strategy help with circularity for Rolls-Royce?

Andrew Clifton: Hugely. Our servitised 'TotalCare' business model means that we are driven to prioritise repair over replace. Repair is often much more cost effective and carries huge reductions in overall impact. These benefits are passed on to the customer and we all gain from the approach. On top of the more complex repair that we carry out at shop visits and engine overhaul, we have also developed innovative 'on wing' repairs using boroscopes and even lasers (to re-finish blade damage without needing to dismantle the engine). This improved engine availability, reducing delays and maintaining high levels of engine performance - all while extending part life and avoiding the need to replace with new.

Mr. Clifton, does the revert programme decrease your costs of raw materials? If yes, can you provide an order of magnitude?

Andrew Clifton: Yes. I can't provide a figure but the saving is greater than the value of the material on the scrap market. This is made possible by the high quality of the material we return to the supplier - it's not contaminated, and it is certified as being a specific alloy type.

Mr. Clifton, what fraction of the alloying elements are lost/diluted, or asked differently: what fraction of virgin elements need to be added per cycle?

Andrew Clifton: It varies. In manufacturing, we typically capture and recycle 95-100% of chip and swarf for our Ti and Ni alloys. End of life parts can have higher losses due to the extra processing that is needed to extract the alloy. Some components (such as discs and other 'critical rotating parts') often have limits on their recycled content. This is driven by safety. Other less sensitive parts can use more.

Mr. Hagelueken, we see your interesting work on recovery of CRMs in products where the design allows easier access. How about electronics?

Christian Hagelüken: Actually it's less about the design, my main point was on the importance of business models. The chemical process catalysts are managed in a closed loop B2B environment among highly professional industrial actors. Due to the high metal values involved, for the manufacturer of the catalysts recyclability is a must from the very beginning. Also the user is fully aware of the value (and price volatility risks) and as he retains property of the PGMs he has a high interest to select a high quality recycling/refining service provider and keep the PGMs in the loop. So all stakeholders involved have a common interest in keeping the value, creating transparent material flows and to closely cooperate. This also fosters "Design for recyclability". In case of electronics we usually have a B2C environment, after having sold the electronic device to a customer there is hardly any link any more between the manufacturer and the customer (especially after warranty period has ended). And at EoL there is no link to the recycler, the stakeholders do not collaborate along the lifecycle, there is little interest in transparent material flows and in design for recycling. Even if a manufacturer would produce an electronic device which is well designed for recycling he hardly would benefit from this as in the current B2C situation he will not get it back himself, at EoL it will be mixed with all kinds of other devices and is – if at all – collected at a municipality. Indeed, also for electronics a B2B business model, i.e. selling the service instead of the product ("lifelong leasing") could help to better close the loops for CRMs. It would create an inherent interest for the manufacturer to design for longevity, repairability and also recycling – and it would create much more transparent material flows and significantly increase the collection rates. Also today, from e-scrap a number of CRMs can be recovered, if the devices are comprehensively collected and channelled to state-of-the art recycling processes only. With a better "design for disassembly" (which is also beneficial for repair) more (critical) raw materials could be recovered with higher yields (e.g. having a removable battery in a smartphone.

Ms. Meese-Marktscheffel, machining is essential for our low carbon equipment manufacturing. Do you think the importance of W is understood in Europe?

Julia Meese-Marktscheffel: In particular, in Europe hard metal (tool) industry is a long time existing "conservative" business, but as far as I know it from our customers, it is well understood that lowering carbon dioxide footprint (I think this it what you meant with your question) is one of the worldwide challenges in the near future, and for sure, especially for us in Europe as high tech industrial countries area. Machining will continue to be essential, however applications (internal combustion engines vs EV traction with electric motor drive/battery management systems) and also tool manufacturing technologies (selected conventional powder metallurgical based tool productions vs new competitive technologies in additive manufacturing) might change. With regard to importance of low carbon dioxide manufacturing: for example, HCS Tungsten is currently also participating in a just started project cooperation in which the energy efficiency along the whole tungsten value chain from the raw material (ores/scraps) till the finished tool is investigated to discover/point out the areas with the highest potential to improve further the carbon dioxide footprint. This project is subsidized by the Federal Ministry of Economics, Germany, being a part of the program "Application-oriented non-nuclear research & development within the 7th energy research program of the federal government of Germany", with 6 consortium partners out of the hard metal/tool industry and 2 research institutes. Within HCS Tungsten processing itself, we have every year distinctive light house R&D projects to optimize our own internal energy needs and therefore to lower our own carbon dioxide output and to contribute eventually also to a lower carbon dioxide footprint over the whole tungsten value chain.

In the EU CRM assessments 2017-2020, we see Tungsten increasing in economic importance, but not reducing much in supply risk. What actions can / should we take?

Julia Meese-Marktscheffel: Procurement should be experienced and well connected. Spot market should be just used to cover short term scrap demand. Long-term and tolling contracts can help reduce supply risks. Technological set up for recycling should be able to deal with all kinds of scrap and scrap ratios (hard scraps, soft scraps, heavy metals, catalysts, etc.). Processing should be improved by new innovative technological approaches to foster sustainability also in recycling and to also lower CO2 footprint eventually. Responsible care is also a very strong point in a reliable "raw materials" procurement, therefore HCS Tungsten, e.g., is regularly audited by the Responsible Minerals Initiative (RMI). For the time being recycling quotes for tungsten containing chemicals, as mentioned, are quite low. Hence, to further increase and to stabilize recycling rates and to lower supply risks circularity with regard to also chemical applications of tungsten containing compounds (e.g. catalysts ex oil & gas industry) should be strengthened. Holistic, highly flexible recycling should be targeted, not only focusing on tungsten but also on other valuable elements like Ta, Co, Ni, …

Mr. Rollat, have you considered what effect the widespread deployment of product life extension strategies, might have on your supply of end of use product?

Alain Rollat: The market study has been done with the technical support of Deloitte who took the responsibility of the lifetime of the products. I am not sure about all the hypotheses they took, but I know that they integrated the evolution of the lifetime of the main products.

Mr. Rollat, why did you chose the pyrometallurgical over other processes?

Actually we chose a mixed pyro-hydrometallurgical process (see the slide here[4]). The target of the pyro part is to improve the removal of Fe during the hydro part. Indeed, by controlling the pyro step you can transform Fe into very insoluble species. You also have not to forget that the oxidation of FeNdB alloy is very exothermal, meaning that if you are able to control the oxidation reaction the external calories to add are low.

Ms. Schrijvers, Circular is not always sustainable. Societal aspects have not been well addressed in the presentations today. Why is that aspect missed?

Dieuwertje Schrijvers: Societal or social impacts have not been the focus of my research, which is why it was not mentioned in my presentation. Social impacts could be evaluated via a Social Life Cycle Assessment. This type of assessment is relatively new and not yet mainstream, as is Environmental LCA. Guidelines on how to conduct a Social LCA were first developed in 2009 with support of UNEP, and are updated in 2020. Now, mostly large companies that aim to be a frontrunner in this field develop UNEP-based methodologies in-house, making it difficult to compare studies at a wider scale. I hope that with increased experience it becomes more widespread to conduct a Social LCA, making it also easier for companies to conduct such a study.

Ms. Schrijvers, if a company succeeds in creating a market for by-products, won't this mean their environmental impact will increase as their economic allocation will?

Dieuwertje Schrijvers: Yes, changing prices is often mentioned as a drawback of economic allocation. Most people apply this type of allocation because they want to reflect who is to "blame" for the process to exist, and hence it's impacts. The relative economic value is considered a good proxy for the relative contribution to the existence of a process. If a product becomes more valuable because new applications are found, it becomes more worthwhile to extract the by-product and the revenue becomes an additional motivator for the process to operate, so an increased environmental footprint could be justified.

Ms. Schrijvers, what amount of recycling activities should be allocated to the EoL product (instead of the recovered elements)?

Dieuwertje Schrijvers: There are different allocation strategies that can be applied. In my presentation, I mentioned economic allocation. I compared the revenue generated by the primary lamps (the EoL product) with the revenue generated by the recovered rare earth elements and it appeared that 97% of the impacts of the life cycle (including the recycling activities) should be allocated to the lamps. You can read my publication for the details.[5] Another strategy to distribute impacts is 'the cut-off approach', in which impacts of collection are allocated to the EoL product and the subsequent recycling entirely to the recovered elements. This procedure is popular because it's easy to apply. However, I think it's not in line with a full Life Cycle approach and difficult to justify when the LCA ISO standards are followed to the letter.

Ms. Schrijvers shows 'stockpiling' as a CRM strategy. Who should set up and control stockpiles? Companies or governments?

[4] https://irtc.info/wp-content/uploads/2021/12/image.png
[5] https://link.springer.com/article/10.1007/s11367-021-01884-3

Dieuwertje Schrijvers: Actually, the stockpiling mentioned in my presentation is different than the stockpiling as a CRM strategy. In my research, I tried to investigate which process will be affected if an additional unit of a recycled rare earth element would be put on the market. Due to the balance problem with rare earth elements, there is a surplus of some rare earth elements and a shortage for others. A surplus is there for example for lanthanum and cerium, because their concentration in the ores is relatively high, and mining is mostly motivated by for example the demand for neodymium. That means that the REEs produced in surplus are stockpiled, or stored. Increased recycling will only contribute to this stockpile, it won't lead to decreased mining, nor to an increased use of the element in an application. On the other hand, strategic stockpiles of CRM could be done when a shortage is expected, so this could be the case for neodymium or dysprosium. However, strategic stockpiling could be considered as a "buffer" to demand: increased recycling will help in filling those stockpiles and maybe slowing down supply from mining. So we should distinguish between stockpiles due to surplus production (relevant in LCA) and stockpiles due to concerns regarding supply security (for CRMs). It think there could be arguments both for company and government-led stockpiling. Governments could stockpile for technologies and sectors that are vital for the economy, whereas companies should also take responsibility in maintaining a sustainable business considering to-be-expected market fluctuations or shortages.

Mr. Sabur, what is your view on the usefulness of the SCIP database (by ECHA)?

Mesbah Sabur: I believe the SCIP database is very valuable, but not having the impact it could have. As the database is connected to individual products, waste operators still have no automatic way of retrieving real time data about products and making efficient sorting decisions. So it's an important piece of the puzzle, but incomplete without being connected to individual products.

Mr. Sabur, could / should policy makers require all products / materials to have a QR code?

Mesbah Sabur: I believe that would be a natural next step for things like EEE products, which already require a EEE mark (the one created by WEEE FORUM). However, for QR codes to be relevant, other important challenges need to be solved first, such as digital product passports (see the work of PCDS in Luxembourg) and traceability (which is what we focus on).

Mr. Sabur, the data transparency you presented would work at best if all manufacturers will use it. How would this be achieved? EU regulations may help?

Mesbah Sabur: We strongly believe that the future of transparency should be based on open digital protocol the same way email communication happens based on the open IMAP and SMTP protocol. This ensures that no single commercial company becomes too dominant (users can freely choose Gmail, Outlook, ISP Email, Apple Mail, etc. without worrying that they cannot send messages to other users). Unfortunately, the transparency industry is headed very strongly toward a closed market, where the natural outcome is 1/2 commercial solutions dominating (essentially the Facebook for circular economy). This is a disaster waiting to happen. Regulation would definitely help. Also funding our open source, non-profit foundation would help creating an open standard.

Mr. Walrecht, do you feel a large consultancy has sufficient flow of staff into organisations to offer sufficient depth of knowledge on critical materials & CE?

Arnoud Walrecht: We are recruiting heavily at the moment in the sustainability and circular economy space. However, we also often team up with other smaller consultancies or academia.

Mr. Walrecht, Circular Economy is needed to get net zero – but is it sufficient?

Arnoud Walrecht: Circularity supports carbon mitigation strategies. That is an underappreciated potential contribution though (COP26 as exemplary). Circularity is not the sole answer in any way, energy systems need to transition for example. My pledge is to apply circular business models to those carbon mitigating investments because of the sustainable raw materials lens.

Mr. Walrecht, why does KPMG focus first on 'material recovery' and not first on 'product life extension'?

Arnoud Walrecht: This is not a time-bound approach in the Circular Transition Indicator framework. The methodology applies three lenses to determine the level of circularity. 1. Circular inflow, 2. Potential recovery (circular design) and 3. Circular outflow. Product lifetime extension (or longevity) will be added to the CTI v3.0 and 4.0, specifically relevant for electronic equipment or assets. This is one of the hardest circular economy components to translate to universal metrics. Please visit the webpage on the CTI framework[6] to stay updated.

Mr. Sahai, if the BEV service is so profitable, is it still attractive for the end-user?

Rajarshi Sahai: I will deconstruct this question and answer it in a – hopefully – logical manner:
a. Are battery electric vehicles profitable? – Given the current costs of energy (electricity) versus petroleum derivatives (natural gas, petrol, diesel), BEVs indeed are a lot more profitable to operate. Depending on (a high) mileage, their total cost of ownership is also very low, compared to ICE vehicles. With a smaller, simpler BEV like ACM, it is possible to further improve on the profitability.
b. Are they attractive for our customers? - Fleet operators across the world have shown confidence in the ACM concept by sharing with us MoUs and LoIs that are worth more than 230,000 vehicles already. In many markets we are being seen as a solution provider that helps bring a lot more money in the hands of drivers and operators and hence reduce the churn out from the industry.
c. Are they attractive for the end consumers? - We strongly believe that sensible electric vehicles in shared fleets are the best thing for end consumers. They get a cheaper service in a quieter and relatively more spacious vehicle and the sense of content that they are helping reduce the pollution. The testament to this phenomenon are the BEV fleets and BEV only services that have come up in various cities of the world, and all with relatively better customer satisfaction figures!

Does intercontinental shipping of raw materials in these days become critical to maintain supply chains in companies?

Leah Charpentier: Volatility in freight prices is a problem for the entire PV industry. We have seen freight prices increase by over 500 percent since the beginning of the year. As manufacturers of components, this is an increase in our operating costs. For PV system developers this means delays and penalties. Solving the freight problem requires massive investment in the shipping and port infrastructure. In the meantime, companies find contingency plans to hedge against this continued risk.

Could collaboration with competing companies be beneficial to facilitate circularity of raw materials, e.g. by sharing expertise or economies of scale?

Leah Charpentier: Many of the most creative clean energy business models are built on collaboration between different economic sectors: for example, what Google and Microsoft are doing in the energy space is fascinating. In this fast-changing space, yesterday's customers can become tomorrow's competitors. For PV specifically, tandem technologies (where different PV semiconductors are stacked to produce more efficient solar panels) will require technological collaboration among former competitors. Getting the legal framework around these partnerships is an essential prerequisite for these collaborations to deliver much needed technological innovation. We must keep in

[6] https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Metrics-Measurement/Circular-transition-indicators

mind however, that these innovations must be remunerated in the market, and the IP associated with these collaborations protected.

It seems to be a common problem for closing the loops on electronics, solar panels, batteries, ELV: how to encourage OEMs to design for recycling?

Leah Charpentier: OEMs already design for recycling where this behaviour is rewarded. Sometimes standalone justifications encourage recycling, the protected supply of critical raw materials is an obvious example. But most often recycling requires buying recycled feedstock which is more expensive than virgin materials, or taking on reverse logistics cost which competitors won't. The problem is the standard economic problem linked to externalities.

Hendy Kim: It is not an easy question how to encourage OEMs to design for recycling. Authorities could simply enforce OEMs to do, but strong resistance is expected from OEMs. Instead, they can provide guidance on recycling-friendly design. A label, for example, listing the composition of cathode active materials inside will be helpful for recyclers. In addition, design for recycling should be improved through constant discussion between authorities and OEMs.

Christian Hagelüken: The best incentive for better design would be a B2B environment with product-service-systems. In addition, the creation of meaningful recycling labels would help, but having a product designed for recycling will not mean that I will be automatically well recycled at its EoL. So we would need a new way of extended producer responsibility where the producer is really obliged to take back and get recycled all his products, so to secure a really comprehensive collection at EoL followed by a proven high quality recycling. This would create an inherent incentive for better design.

7 Plenary discussion

The plenary discussion took place after the talks and was continued for an hour after the broadcasting ended. Due to technical reasons, the possibilities for input of the online participants, including the online speakers, was limited.

7.1 What incentives can encourage OEMs to design for recycling?

Leah Charpentier: Product passports to demonstrate high recycled content, allowing companies to differentiate. Incentives are needed at the sales side to cover the costs of reverse logistics and recycling. High price volatility of CRMs alone is not sufficient.

Nathan Williams: Companies that are active in recycling are new companies. For existing OEMs, it is much harder to change their processes that are in place for many years. This resistance to change limits the effectiveness of positive incentives for new business models. The alternative is negative incentives, e.g. legislation or making companies accountable for their externalities through pricing.

Arnoud Walrecht: Besides regulation, structural economic changes are needed. The tax system should change to lower the cost of labour and increase the costs of resources.

7.2 What is the potential for products as a service? And where are the challenges?

Thea Kleinmagd: A repairable phone can be maintained more easily, but at the same time large up-front investments are needed. Fairphone has been investigating a leasing model for two years. Next year, a pilot will start to hopefully prove that it is financially viable.

Leah Charpentier: First Solar has a long-lived product. Recycling has benefits for the long-term relationship with utilities. This is much harder in decentralized markets, as decommissioning roof-top panels is more expensive.

Rajarshi Sahai: EVs have fundamentally changed the market. The traditional operating-lease model has frequent maintenance and repair moments. EVs need maintenance after 3 years only, increasing the profitability. The increasing prices of used cars and the rapid demand growth are in favour of leasing and sharing models.

Christian Hagelüken: One of the biggest chances to improve design for recycling are the business models. The success factor in the cases of Umicore, Rolls-Royce, Kyburz is the B2B environment. PGMs are very well recyclable by themselves, but the incentives to recycle the products comprehensively arise because the producer keeps ownership. This requires that a leasing model has to last until a product's end of life.

Arnoud Walrecht: There are different incentives for different types of circular business models. Paper-use type of models provide the most intrinsic economic incentives.

7.3 Can consumers be motivated to support recycling by showing the intrinsic value of secondary materials?

Ajay Patil: The success depends on two key factors: the initial investment is made by the end-user, and the recycling costs are covered. Because of the investment, consumers are inclined to pay for a service to recover value at the end of life.

7.4 Could collaboration between competing companies be beneficial for raw materials circularity?

Rajarshi Sahai: Whenever an industry is in a transition, the traditional competition model does not work. A monopoly is limited by the scale of one company. So when new industry segments are created, we ideally need a choice model, to mobilize the latent demand.

Lea Charpentier: First Solar has tailored their process to their own technology. The main objective is to recover the semiconductor. For the by-products of recycling, the incentives are low. For the societal optimization, a discussion is needed. The regulator needs to set some rules to allow companies to recoup investments in recycling.

Nathan Williams: The EU REACH regulation helped large companies to share information about hazardous chemicals with competitors without facing anti-trust issues. By creating dedicated departments, data exchange became possible. To make recycling feasible, companies either need to differentiate based on it or regulation is needed. The first option doesn't allow for collaboration. In general, the business case for recycling is not fully established, so creativity is needed. We need to move away from differentiating based on recycling efforts, but that will take time.

Jeroen Cox: KPN can cooperate to standardize criteria for circular procurement. Five or six years ago, the joint audit cooperation started to audit labour conditions. Nowadays, this cooperation involves 17 telecommunication companies, representing 40% of the industry, and it is moving towards circular economy and net zero. The participants are exchanging knowledge on a conceptual level (to address anti-trust) and discuss standardized questions to ask. This can induce changes higher up in the value chain.

7.5 How can we avoid that the industry recycles just to reach recycled content targets, without a real transition to circularity?

Mesbah Sabur: I propose a carbon tax, because companies that focus on targets will respond to economic incentives.

Leah Charpentier: Recycling is a cost, which is a competitive disadvantage that should be levelled. Recycling targets and taxes are not ideal, but economic benefits must be created to cover recycling costs. Investments in public benefits can either be made by public bodies or by compensating private companies.

Dieuwertje Schrijvers: Recycled materials often have a lower footprint than virgin materials, raising the question whether these benefits should be allocated to the producer or the consumer of recycled materials. Recycled content targets could lead to a diversion of waste flows rather than increasing overall recycling. To avoid this, we need to know if the demand or the availability of recycled material is the limiting factor.

Rajarshi Sahai: The challenge is to consider manufacturing and operations combined. We should question the need for a product and the amount of material that is used for manufacturing. Ways to manufacture less and share more should give the same benefits as recycling.

The Kleinmagd: Fairphone uses post-consumer recycling as an indicator, to avoid excessive pre-consumer recycling. Take-back of Fairphones is incentivized. This comes at a cost, but is also used as a unique selling point. The Fairphone 4 model is sold with the promise of e-waste neutrality. This strategy attracts eco-conscious customers and raises the expectations towards other phone manufacturers.

Olivier Groux: In Switzerland, consumers pay a fee of €1.50 when purchasing a battery. This amount is rewarded to the company that recycles the EoL battery. This system can be applied elsewhere.

Nathan Williams: Every problem that we face today is the unintended consequence of a problem that we solved yesterday. While there is a legitimate fear for fraud with recycling incentives, we cannot anticipate all possible issues. Therefore, we should take actions today and accept that they cause some unintended consequences.

7.6 How can and should regulation incentivise circularity?

Leah Charpentier: We are dealing with disruptive business models in an environment where rules have been designed and optimized for a linear economy. Regulations should level the advantages the established companies have toward disruptive ones. Regulation should not pick the winners, but create an enabling environment that is not being naïve about the fact that there are externalities. If for political reasons we want more recycled content, policy must help that there is a viable economic environment for recycled products without putting the burden of complicated paperwork on it. Crossing borders must be facilitated and regulations should be streamlined across Europe; otherwise every Member State will have to build up their own B2B environment. Governments must share the burden of building the necessary infrastructure, and create an environment where people can compete on the basis of what they are offering in line with who is being most effective in reaching the policy objective. The problem with regulators is that new business models are risk-bearing. Rules that are against equal access and based on linear business models must be amended. And anything that gets in the way of a single market of recycled products and RMs needs to change – at the moment, a EU waste single market does not exist.

René Kleijn: The more generic a measure is, the better it is, because it is less prone to pick winners. Carbon pricing, for example, can reward recycling through its smaller CO_2 emissions compared to mining.

Nathan Williams: Regulation is always picking winners: no matter what gets codified, someone will benefit and someone will not. On the other hand, as soon as regulation settles and is around it for some years, people will find loopholes and trick incentive-based systems, even if regulators do their best to avoid those loopholes. The idea behind regulations such as REACH is data: everyone has the right to know what they are purchasing.

Constanze Veeh: There is a fine line between the need to regulate and over-regulation. Many sectors, such as chocolate or coffee, developed their own labelling schemes, because they are rewarded by consumers. Not a regulation but business initiatives on more openness and transparency are behind these schemes. Of course not in every sector has a direct end-user with buying power, but still there can be value for the business to be active in such schemes as a selling point and to de-risk for the future. Paper and glass recycling, as another example, originates in these very industries recognising the value of their material and pushing for collection and recycling; not from a top-down regulation.

Rajarshi Rakesh Sahai: Many companies have today more value from arbitrage than from manufacturing. More agile response from policy-makers are needed here. They have to me more principle-based and fair, also from a global point of view. Responsibility does not stop at the border; the second life e.g. of cars in developing countries has to be taken into account.

Ajay Patil: The main problem with CRMs exists because we lost the manufacturing processes and the know-how in Europe, which is crucial for future and current businesses. Rebuilding this knowledge starts with technological and financial risks, for which a level playing field is needed. International patent protection can hinder development of circular strategies, especially if they are only followed by a few countries.

Roderick Eggert: The presumption behind much of the discussion today is that more recycling and circularity is always better. This might not always be the case. One has to ask about the externalities associated with non-recycling and the best mechanisms for internalizing these costs, thus enabling sound private decision-making. Government support can have different angles, such as the public subsidizing the collection – since cost of collection is the biggest barrier to recycling – or fees that make recycling more economic than non-recycling. A variety of small activities can facilitate higher recycling rates and should encourage when it makes sense to recycle more, while also recognizing the point where recycling might already be sufficient, or not the best choice.

7.7 Should regulations make data disclosure mandatory?

Leah Charpentier: First Solar is in a better position to ensure transparency than Chinese competitors because of its shorter supply chains – they have just 3 tiers instead of 7, as part of the company's business models. Data has to be used to deal with externalities. This is where the regulator has to come in to ensure a level playing field.

Mesbah Sabur: The goal should not be to collect all company data and store it at a central place; this will violate company confidentiality and regulate companies out of their business. Companies do not want to share data on a public ledger. But design for privacy is possible, and there are technological ways to safeguard confidentiality by ensuring for transparency where needed, and validating crucial information where compliance is required.

Dimitru Fornea: Big data about companies should not be connected, as it subordinates everyone to the AI, and centralizes the power. Individual company interests are also societal interests.

7.8 Can circular economy be an opportunity for companies?

Thea Kleinmagd: Things like a faitrade label are important and can be a strategic asset. It shows that a company is not only avoiding risks but actively engaging.

Carlos Peiter: The Circular Economy is not a big topic in Brazil for mining companies yet, as seen from the 2021 Brazilian Mining Congress program content, with just one session devoted to such issues. On the other hand, companies are considering hundreds of potential sources of minerals to be assessed as new available deposits. For instance, the average amount of tailings generated in Brazil per year, just from the main mining production of iron, copper, bauxite and gold, is presently around 3.4 billion tons, as well as 8.2 billion tons of waste rock. These might be seen as potential target reserves of remaining minerals discarded due to low content, or low market price, or present processing/logistic problems. For instance, some large mining companies in Brazil are starting partnerships with other companies to sell by-products with reduced royalty rates, applying recent regulation connected to national royalties law to improve recoveries from tailings and waste rock.

Magnus Ericsson: We should not forget that the mining in developing countries offers a window of opportunity for some countries. The industrialised nations built their wealth on their mining sectors. Maybe no one will need Cobalt anymore in 50 years, so the window of e.g. the DRC to build on their mineral wealth and escape their poverty stemming from the colonial history is limited. Recycling is not necessarily the fairer and more sustainable option; different aspects have to be balanced. This is similarly true for domestic exploration: investing in developing countries and ensuring supply might be a better contribution for global sustainability.

Leah Charpentier: The supply risks of CRMs are one of the main drivers for recycling in the PV industry. PV technology will continue to change a lot, and CRMs might just be used in small quantities for doping purposes – but nobody knows exactly yet how these chemistries will look like. The answer must not be moral but economic: unless secondary raw materials must be price-competitive, not much will change.

Dimitru Fornea: In the EU, carbon emissions are now a key fact in light of competitiveness. Increased circularity can thus be an opportunity to comply with Fit for 55.

Patrick D'Hugues: When we talk about sustainability – environmental impacts, tailing dams, child labour, and so on – we have to more or less agree on what we consider sustainable. We need tools to monitor as well. A clear definition is crucial so that companies can actually benchmark their progress. The EU Principles of Sustainable Raw Materials are a first start on this.

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