Products, Technologies, and Normative Requirements for Recycling of Valuable and Critical Raw Materials

Dr. Otmar Deubzer[*1]; Steven Art[2]; Yifaat Baron, Dr. Matthias Buchert, Inga Hilbert[3]; Lucia Herreras[4]; Shahrzad Manoochehri[5]; Lindsey Wuisan[6]; Norbert Zonneveld[7]

[1] United Nations University SCYCLE, Bonn, Germany
[2] Umicore, Hoboken, Belgium
[3]Oeko-Institut, Freiburg, Germany
[4]WEEE Forum, Brussels, Belgium
[5]World Resource Forum Association, Geneva, Switzerland
[6]ECOS, Brussels, Belgium
[7]EERA, Arnhem, The Netherlands
* Corresponding Author, deubzer @vie.unu.edu, +49 30 417 258 33

Abstract

Recycling rates of most critical raw materials (CRMs) as defined by the EU are close to zero, while the demand for many CRMs is growing in various sectors. the recycling contribution is largely insufficient to meet the demand.[1] Recycling is considered a risk-reducing measure.[2] The EU-funded H2020 project CEWASTE (www.cewaste.eu) contributes to improve the recycling rates of CRMs from e-waste and batteries by producing and pilot testing requirements for collection, transport and treatment of products containing sufficiently high concentrations and amounts of critical raw materials. In a first step, these products – the Key CRM Equipment (KCE) – were identified, and current normative requirements analyzed for stipulations that could be referenced. This paper describes the approaches and results of these activities, which form the base for the development of KCE-specific CEWASTE-requirements (c.f. paper of Sonia Valdivia, World Resources Forum, "Sound recycling and transboundary movements of WEEE containing critical raw materials - CEWASTE Requirements"). To enable certifications of operators working according to these requirements, an assurance and verification system will be created (c.f. paper "CEWASTE Assurance and Verification System for the certification of waste management operators with CRM focused requirements" of Yifaat Baron, Oekoinstitut). This system and the requirements will be pilot tested with several treatment operators (ongoing) and then be finalized taking into account the collected experiences.

1 Introduction

The 2017 EU-list of critical raw materials (CRMs) includes 27 materials. [2] Their recycling rates from waste products are, however, low. [1] Since recycling is one approach to mitigate the criticality of CRMs, the CEWASTE project aspires setting up and establishing requirements for a standard and a verification system for the collection, transport and treatment of products containing CRMs to enable their recycling and to create a level-playing field for the operators along the end-of-life (EoL) chain. At the same time, the requirements shall – besides the recycling of palladium listed as CRM – also improve the recycling of other valuable materials.

2 Product scope and selection of waste products for CRM recycling

The volumes of electrical and electronic equipment (EEE), waste batteries from EEE and end-of-life vehicles (ELVs), and engines of electrical ELVs are growing rapidly, and it is foreseeable that this trend continues. At the same time, these products use many CRMs while the recycling rates are very low. E-waste, waste batteries and engines of electrical vehicles were therefore selected to further evaluate from which from those devices and their components recycling of CRMs might be feasible. For the evaluation, the consortium set up conditions which waste products have to meet in order to qualify as Key-CRM-Equipment (KCE).

2.1 Criteria for KCE

Waste products need to match with the following criteria to qualify as KCE:

1. The final treatment must be technically feasible. This is considered to be the case if a processing technology has achieved a (technology readiness level (TRL) [3] of at least 7) so that an adequate industrial scale final treatment is possible already or verifiable in the near future.
2. Collectors and pre-treatment operators must be able to provide the input which the end treatment processes require for the recycling of the CRMs. In most cases, this will imply that the pre-treatment, with support from collectors e.g. by sorting of KCE, yields a fraction with sufficiently high concentrations of CRMs in a form from which the end treatment operator can recycle CRMs.
3. The product or at least one component (CRM source component) contains relevant concentrations and amounts of CRMs. If CRMs are concentrated in components, they can be separated from the KCE prior to further pre-treatment steps to avoid CRM dilution and to maintain or achieve a sufficient concentration which enables the CRM recycling in the final treatment.
4. The economic feasibility under the current economic framework conditions is no obligatory criterion to be met since economic conditions can be changed. Prior to the enactment of the WEEE Directive, for example, the sound treatment and disposal of e-waste was economically not feasible in many cases. The WEEE Directive ensured the proper financing by introducing the extended producer responsibility (EPR) thus installing a stable financing mechanism. Increasing the recycling rates of CRMs will require political decisions improving the economic conditions of collection, transport and treatment of KCE if recycling of CRMS shall actually be achieved.
5. Despite of the above criteria no. 3. and 4. , CRM-containing products must have relevant concentrations and contents of CRMs to keep a reasonable balance between benefits and efforts/costs for CRM recycling. E-waste with very small CRM-containing components which have to be separated from a printed circuit board (PCB) to enable the recycling of the small CRM content therefore cannot qualify as KCE as long as it causes excessive costs to obtain tiny amounts of CRM. E-waste containing tantalum in capacitors could, for example, not qualify as KCE for this reason.
6. CRM recycling shall not be conflicting with precious metal (PM) recycling. PMs are the economic backbone of the e-waste recycling business, and they generally have a huge environmental backpack affecting the overall environmental impact of EEE and other products.[4] Sacrificing PMs for the sake of CRM recycling thus would be an economically and ecologically questionable decision. The case of tantalum capacitors exemplarily can illustrate the economic situation and the conflict with PM recycling. PCBs may contain very small tantalum capacitors as well as relevant contents of PMs (gold, silver). Tantalum and PMs require different final treatment processes to enable their recycling. Tantalum recycling would thus be possible if the entire PCB went into tantalum recycling resulting in the loss of the PMs. An alternative scenario would be separating the tantalum capacitors from the PCB. This alternative was found to be inadequate due to the economic imbalance of the separation efforts on the one hand and the very small yield of tantalum on the other hand at the current state of technolgy. PCBs with tantalum capacitors therefore could not qualify as KCE/source component for tantalum.

2.2 Key CRM Equipment

For the CRM concentrations and contents in the selected product groups, the consortium could revert on data from the ProSUM [5] and SCRREEN [6] projects as well as the database of Umicore Precious Metal Recycling.

The below table 1 lists the KCE identified according to the above criteria and the CRMs in their source components.

Table 1: KCE and source components

Source Component	KCE	CRMs	Current Economic Feasibility
Fluorescent powders	Fluorescent lamps	Eu, Tb, Y, Ce, La	No
	CRT monitors and TVs	Y, Tb, Eu, Gd,La, Ce	
Nd-magnets	Temperature exchange equipment (compressor)	Nd, Pr, Dy, Gd, Tb	No
	Household appliances other than temperature exchange equipment (motors/drives)		
	Laptops (HDD)		
	Desktop Computers, prof. IT (HDD)		
	BEV, (P)HEV (electro engine)		
PCBs	Desktop computers, prof. IT	Au, Ag, Bi, Pd, Sb	Yes
	Laptops		
	Mobile phones		
	Tablets		
	External CDDs, ODDs, devices with internal CDDs/ODDs		
Screen	Mobile phones	In	Yes
Li-ion batteries	Laptops	Co	Yes
	Mobile phones		
	Tablets		
	Li-ion batteries in other WEEE		
	BEV, (P)HEV		
NiMH battery	NiMH batteries in WEEE	Co, (Ce, La, Nd, Pr)	Yes (Co) / No (REEs)
	HEV		
Lead acid batteries	Lead-acid batteries	Sb	Yes

2.3 Current KCE treatment practices and abilities

Recycling of palladium and other PMs from printed circuit boards is daily practice in e-waste treatment. Further, cobalt is recycled from lithium-ion batteries in industrial scale.

Recycling of fluorescent powders from fluorescent lamps had been practiced until 2016 before the operations were stopped for economic reasons. The price decrease of REEs after the peak in 2011 undermined the economic base of these recycling operations.[7] These past recycling activities prove, however, that the recycling of REEs from fluorescent powders is technically feasible with an established technology. Since the operations had been stopped, it could not be clarified whether the previously installed commercial REE recycling process would have been appropriate for CRT fluorescent powders as well. Another operator reports to run a plant which could process 400 t per year [8] of fluorescent powders from CRTs and from fluorescent lamps for REE recycling in case the financing would be ensured.

Different from other CRM-components, the TRL of NdFeB-magnet recycling is lower than 8. REE recycling from NdFeB-magnets thus is technically feasible, but the economic feasibility may be critical under the current economic conditions.

Hitachi Metals has developed a pyrometallurgical method in Japan using molten Mg as an extraction medium to recycle Nd and Dy from NdFeB-magnets. Santoku Corporation is said to have started in 2012 a recycling route for neodymium and dysprosium from magnets of air conditioner motors and magnet production scrap.[9] Details about the actual status of these processes are not available.

Another process for recycling of REEs from NdFeB-magnets is Momentum's hydrometallurgical MSX technology process. The MSX technology was reported to be capable of recycling more than 99 % of the rare earth content from HDDs dissolved in acid while operating at room temperature and pressure.[10] Finally, the Ames Laboratory acid-free dissolution recycling technology is described as having the potential to recycle Nd from shredded HDD samples without pre-concentration of the magnet contents, even though a pre-concentration is desirable to reduce the amounts of chemicals needed.[11] Both processes produce mixed REE-oxides, which are less favorable for NdFeB-magnet production than separated ones. Several EU-projects address recycling of REEs from magnets, e.g. REE4EU (pilot scale plant [12], REEcover [13], and others [14]).

Besides recycling REE from NdFeB-magnets, waste NdFeB-magnets can be used to produce new NdFeB-magnets. A US-based company claims to have commercialized its process for producing recycled sintered NdFeB-magnets with their patented Magnet-to-Magnet process [15]. In the EU, the SDS-process [16] (Shaping, Debinding and Sintering process), another process to produce new NdFeB-magnets from waste ones, was developed in the ReproMag [17] project. The development is being continued in the SusMagPro [18] project.

Further principle alternatives are the reuse of NdFeB-magnets from HDDs in applications others than HDDs, or the reuse of NdFeB-magnets from HDDs in newly produced HDDs.[19] HDDs are, at least in consumer products, more and more replaced by SDDs, which do not use NdFeB-magnets, but they still seem to have a future in the increasing numbers of datacenters around the world.[20, 21].

The CEWASTE consortium expects that the current technological status and ongoing development of recycling processes will soon allow industrial scale operations once the financing is secured and the feeds for these processes are available in sufficient volumes. The commercial application can be assumed to boost the development of recycling more effective and efficient recycling processes so that, in combination with competition in the market, the treatment of NdFeB-magnets may become cheaper over time.

3 Mapping and analyses of normative requirements

To avoid setting up requirements which are already established in other regulations, the consortium identified 55 normative requirements – mainly pieces of legislation and standards - with potential relevance for collection, transport, treatment and disposal of the KCE. Additionally, six verification schemes were found to be potentially useful for the setup of a CEWASTE verification scheme, or to take over the verification of the CEWASTE requirements. The 61 items were analysed for stipulations that could be referenced in the CEWASTE requirements document.

In order to qualify for further consideration, the verification schemes had to comply with the ISEAL principles and the ISO 17 000 series [22] since they represent the core values on which effective sustainability standards are built:

- Sustainability,
- Improvement,
- Relevance
- Rigour
- Engagement
- Impartiality
- Transparency
- Accessibility
- Truthfullness
- Efficiency

Each verification scheme has been contacted in order to assess whether they conform to the ISEAL principles and the CENELEC ISO/IEC 17 000:2004 standards. Three verification schemes have confirmed their compliance: EPEAT, WEEELABEX and JAZ-ANS, the organization who introduced the AS/NZS 5377:2013 standard in Australia and New Zealand.

The WEEE-, ELV- and Battery-Directives, and the CENELEC EN 50625 standards series are the most important normative requirements in the EU. Since the CEWASTE requirements shall also be pilot-tested outside the EU, non-European normative requirements like R2 and e-Stewards were included as well. While many environmental, health and safety as well as documentation and tracking requirements can be adopted from the analyzed normative requirements, in particular specific technical requirements for CRMs generally and for the KCE in particular are largely missing.

A large non-technical gap is the lacking financing of sound collection, and treatment of most KCE, which the EU has to fill if CRM recycling is to happen as one pillar of CE to mitigate CRM criticality.

Further details about the selection of KCE and the analysis of normative requirements are available in Deliverable D1.1 on the CEWASTE webpage.[23]

4 Outlook

The identified requirement gaps for the sound collection, storage, transport and treatment of the identified KCE have been filled in the past weeks, and the development of the assurance and verification system is under way. For further information c. f. the papers and presentations of Sonia Valdivia, World Resources Forum, et al. ("Sound recycling and transboundary movements of WEEE containing critical raw materials - CEWASTE Requirements"), and "CEWASTE Assurance and Verification System for the certification of waste management operators with CRM focused requirements" of Yifaat Baron, Oekoinstitut, et al.).

5 Literature

[1] JRC: Critical raw materials and the circular economy, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108710/jrc108710-pdf-21-12-2017_final.pdf

[2] European Commission: Critical raw materials, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

[3] HORIZON 2020 –WORK PROGRAMME 2014-2015, General Annexes, Page 1of 1, Extract from Part 19 -Commission Decision C(2014)4995G. Technology readiness levels (TRL), c.f. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

[4] Otmar Deubzer: Explorative Study into the Sustainable Use and Substitution of Soldering Metals in Electronics – Ecological and Economical Consequences of the Ban of Lead in Electronics and Lessons to Be Learned for the Future; PhD thesis TU Delft, The Netherlands, January 2007, ISBN 978-90-5155-031-3, http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/

[5] Prospecting Secondary raw materials in the Urban mine and Mining wastes (ProSUM), http://www.prosumproject.eu/, H2020
[6] SCRREEN project: http://scrreen.eu/, H2020
[7] For historical REE prices check http://static5.businessinsider.com/image/5418482469bedd2b4285259f-1200-1000/rare%20earth%20pricing.jpg
[8] Information obtained from RELIGHT https://www.relightitalia.it/en/ via e-mails
[9] For recycling technologies see page 126 et sqq. of SCRREEN deliverable D4.2 (http://scrreen.eu/wp-content/uploads/2018/03/SCRREEN-D4.2-Production-technologies-of-CRM-from-secondary-resources.pdf) and https://www.urbanminingco.com/index.php?cat=about
[10] For details see page 41 of the iNEMI report “Value Recovery Project 2, [https://www.inemi.org/value-recovery-2-final-report
[11] For details see page 41 of the iNEMI report “Value Recovery Project 2, https://www.inemi.org/value-recovery-2-final-report
[12] REE4EU project, c.f video (https://youtu.be/6b0CS65a1Ro)
[13] REEEcover project, https://cordis.europa.eu/project/rcn/110976/factsheet/en
[14] For an overview of EU and international developments also see Yang et al.: REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap; https://repository.tudelft.nl/islandora/object/uuid:92b1afee-41e4-429d-b381-965673f893ef/datastream/OBJ/download
[15] Urban Mining Corporation, for details see pages 31 et sqq. of the iNEMI report “Value Recovery Project 2, https://www.inemi.org/value-recovery-2-final-report
[16] For more information see https://www.youtube.com/watch?v=FWcEjTjSYbE
[17] ReproMag project, https://repromag-project.eu/
[18] Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SusMagPro project), https://sc5.easme-web.eu/?p=821114 and https://www.steinbeis-europa.de/susmagpro_en
[19] For details see Demonstrators 1 and 2 in the iNEMI report “Value Recovery Project 2, https://www.inemi.org/value-recovery-2-final-report
[20] Anandtech: Shipments of PC Hard Drives Predicted to Drop By Nearly 50% in 2019; https://www.anandtech.com/show/14298/shipments-of-pc-hdds-predicted-to-halve-in-2019
[21] For details see Maximilian V. Reimer, Heike Y. Schenk-Mathes, Matthias F. Hoffmann, Tobias Elwert, TU Clausthal: Recycling Decisions in 2020, 2030, and 2040—When Can Substantial NdFeB Extraction be Expected in the EU?, https://www.mdpi.com/2075-4701/8/11/867/pdf
[22] ISEAL, https://www.isealalliance.org/credible-sustainability-standards/iseal-credibility-principles
[23] CEWASTE Deliverable 1.1 BASELINE AND GAP/OBSTACLE ANALYSIS OF STANDARDS AND REGULATIONS, https://cewaste.eu/wp-content/uploads/2020/03/CEWASTE_Deliverable-D1.1_191001_FINAL-Rev.200305.pdf