CRM Raw Material Recovery Trials Executive Summary

Introduction

Each year around 9.9 million tonnes of waste electricals and electronic equipment (WEEE) is generated in the EU. Only 30% of WEEE generated is reported as properly collected and recycled. Many modern electrical and electronic products contain metals which have been classified as Critical Raw Materials (CRMs) by the EC. CRMs are those where supply and their economic impact to the EU is at risk and higher than for other raw materials.

Industry trials sought to demonstrate economically viable approaches to the collection and recovery of WEEE and tested a range of collection and recovery mechanisms to maximise the collection of those products with the highest concentrations of CRMs as follows:

Target Product Categories:

- Display, Consumer Electronics;
- Information and Communication Technologies (ICT); and
- Small Household Appliances

Target Materials:

- Graphite;
- Cobalt;
- Antimony;
- Tantalum
- Silver;
- Gold; and
- Platinum group metals (PGMs).

Five partners were selected through competitive tendering processes, to deliver trials in the UK, Germany, Italy and the Czech republic. Altogether, 13 collection activities and 7 recovery activities were trialed between June 2016 to August 2018.

Collection mechanisms promoted the recovery of CRMs in line with the waste hierarchy (e.g. prioritising product re-use, repair and remanufacturing activities over recycling and reprocessing). CRM-rich and high value materials were aggregated to test the commercial viability of collection mechanisms. Of the products collected, items suitable for re-use were separated and any remaining products were disassembled to target key components, and then prepared for component re-use or further reprocessing. Outcomes from the collections trials were evaluated to determine their socio-economic impact and effect on the re-use and recovery of CRMs. The recovery trials sought to test both novel and innovative methods of CRM recovery and to understand the impact of changes made in the collections, pre-sorting, and concentrating activities on the recovery of target CRMs. Table 1 below provides an overview of the collections and recovery methods tested during the project.

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Table 1 : Collection and Recovery Trials Overview

Trial lead	Collection mechanism	Recovery method	Target CRMs	Location
Axion Consulting	1. WEEE take-back in 5 Dixons stores in the Greater Manchester Area 2. WEEE take-back with charity British Heart Foundation in Greater Manchester Area 3. Incentivised WEEE take-back with John Lewis in Leeds and York	1. De-soldering of PCBs to extract CRM-rich components. Components were then optically sorted and analysed	1. Cobalt, Antimony, Tantalum, Rare Earths, Platinum Group Metals, Gold and Silver	England
Re-Tek	1. Employees bringing domestic WEEE to business WEEE collections 2. WEEE bins at recycling centres 3. WEEE collections at university halls of residence WEEE collection hubs in primary schools	1. Electrodeposition in an electrochemical flow system	1. Cobalt, Gold and Silver	Scotland
Ecodom	1. Consumer events held in public squares across Milan on Sundays 2. School collection hub in Milan	1. Extracting cobalt from Li-ion batteries 2. Comparing outputs from CRM-rich and non-CRM-rich WEEE through existing precious metal treatment facility	1. Graphite, Cobalt 2. Platinum Group Metals, Gold and Silver	Italy
RecyclingBörse	1. School collection hubs 2. Monthly kerbside household collections 3. Collection boxes for households and businesses All activities located in Herford	1. Production of Nd-Fe-B from magnets 2. Extraction of Tantalum from capacitors	1. Tantalum 2. Rare Earths (Neodymium)	Germany
Asekol	1. Mobile collection units in areas of Prague that are unable to have permanent containers due to being in areas of historical beauty	2. Increasing CRM concentration from WEEE reprocessing	1. Rare Earths, Platinum Group Metals, Gold, Silver, Copper and Aluminium	Czech Republic

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Collections

In total around 43 tonnes were collected through the collection trials activity of which nearly 10 tonnes were used to complete the monitoring and evaluation requirements of the project. Although the cost and revenues from the individual trials are not directly comparable due to the differing methods used, they do suggest that collecting high value products (that can be resold with little or no repair) as economically as possible (via a retailer) could offer the most effective means of increasing CRM recovery.

Table 2 below provides an environmental assessment of the collection trials. The total material requirement (TMR) for the products collected and the CO2e emissions for those products are reported, based on the contents of CRMs multiplied by the quantities of products collected, combined with data records from Ecoinvent (Ecoinvent, 2019).

Table 2: Total material requirement and CO2e emissions of collected products

	Collection quantity, kg	TMR of products collected, kg	Specific TMR of products collected, kg per kg	CO_2e of products collected, kg	Specific CO_2e of products collected, kg per kg
Asekol: Mobile Containers	1570	19708	13	15.96	0.01
Axion: BHF	349	8316	24	7.17	0.02
Axion: Dixons	281	7953	28	7.19	0.03
Axion: John Lewis	66	1738	27	1.6	0.02
Ecodom: Market Squares	1321	18437	14	15.83	0.01
Ecodom: Schools	399	7053	18	5.96	0.01
RecyclingBörse: ReBag	163	1115	7	0.57	0
RecyclingBörse: ReBox	95	300	3	-0.02	0
RecyclingBörse: Schools	2134	34100	16	34.8	0.02
Re-Tek: B2B	777	18937	24	19.83	0.03
Re-Tek: Halls	1	26	29	0.02	0.03
Re-Tek: HWRC	2186	55501	25	59.26	0.03
Re-Tek: Schools	169	4782	28	4.4	0.03
Re-Tek: Social Enterprise	345	9170	27	9.3	0.03

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The results demonstrated how context-dependent the potential to save resources or to reduce the climate impact are and that results can vary greatly depending on which impact categories are considered. In addition, there are considerable uncertainties in the calculation of both the quantities of CRM and the environmental indicators, due factors such as human error when assigning products to categories and the poor quality of data available on material compositions for many electronic products.

Development of a product database is recommended, to include knowledge of embedded CRM content and sorting criteria that could be used much earlier in the collection stage, for example in the marketing of the collections to encourage citizens to bring target CRM-rich WEEE for collection and which should also remind them to handle their products with care (to maintain their re-use value).

Economic assessment (Table 3) shows the collection trials were not viable. Whilst this is the case, it should be understood that the nature of the demonstration trials was that they were necessarily small scale and innovative in nature. Larger-scale operations and established technology would therefore not cost as much.

Table 3: Economic assessment of the collection trials

		Asekol	RecyclingBörse			Ecodom		Axion		Re-Tek
						Schools	Market squares	JLP	BHF	
Costs €	Investments/ permits	7000		5400	5000	410			200	
	Media	3000	800	930	300	2000	7236	300	4000	
	Labour costs	32000	4600	1600	6000	2590	4963	200	200	4660
Revenues €	Re-use	304.78	417.5	55	270	78	258	1633	1240	1338
	Recycling	146.99	201.35	5	15	38	125			
Collection kg		1570	2134	95	163	399	1321	66	349	3477
Costs € per kg		26.75	2.53	83.47	69.33	12.53	9.23	7.58	12.61	1.34
Revenues € per kg		0.29	0.29	0.63	1.75	0.29	0.29	24.74	3.55	0.38
Costs excl. investments / permits, €		22.29	2.53	26.63	38.65	11.50	9.23	7.58	12.03	1.34
Cost / revenue ratio excl investments		0.01	0.11	0.02	0.05	0.03	0.03	3.27	0.29	0.28

The collections trials demonstrated that retailers and charity shops have the opportunity to increase collections of WEEE together with retailers that are part of consumer's everyday habits (e.g. small convenience stores) who offer an economical method of collection. Trusted retailers may also provide consumers with confidence to securely deposit data bearing devices (e.g. smartphones) and thus increase the potential economic returns from collections of these relatively high value products.

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It appeared both economically and environmentally sound for collection systems to prioritise and enable re-use markets, over recovery/ recycling. Whilst collections for re-use need to target newer, high specification items with a relatively high resale value, it may be optimal for some collections to target WEEE that have a high concentration of components used, e.g. PCB's, dependent on the CRM recovery process.

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Recovery

The recovery trials set out to separate CRMs from the items collected that had not gone to re-use. New technologies were trialed and demonstrated on a small scale and there were notable successes in achieving high enough concentrations of CRMs for recovery in some cases. The recovery trials were each different and did not produce comparable results, however, Table 4 provides and overview of the trials and their outcomes.

Table 4: Recovery Trials Summary

Trial lead	Recovery method	Target CRMs	Location	Outcomes
Axion Consulting	De-soldering of PCBs to extract CRM-rich components. Components were then optically sorted and analysed	Cobalt, Antimony, Tantalum, Rare Earths, Platinum Group Metals, Gold and Silver	England	• Dismantling of WEEE can be difficult and time consuming, especially for smaller, more intricate items such as laptops and smartphones. • Chemically separation of components containing high value elements from circuit boards is difficult due to varieties in fixing mechanisms and issues with large metal pieces such as heat sinks. • An alternative may be to use thermal treatment to melt solder and other adhesives.
Re-Tek	Electrodeposition in an electrochemical flow system	Cobalt, Gold and Silver	Scotland	• Some of the proof of concept laboratory experiments demonstrated high recovery rates of the elements of interest. • Further laboratory work is required before these separation techniques would be suitable for use within a commercial environment. • A recovery methodology that has several stages may be the most effective at recovering CRMs from PCBs.

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Ecodom	Extracting cobalt from Li-ion batteries Comparing outputs from CRM-rich and non-CRM-rich WEEE through existing precious metal treatment facility	Graphite, Cobalt Platinum Group Metals, Gold and Silver	Italy	• The most effective way to conserve CRMs is through re-use, allowing no losses as the units are given a second life. • Further exploration is warranted into the possibility of setting up organized, reliable and accurate methodologies to perform the preparation for re-use of flat screens. • PMR process recovery trials and battery recovery trials demonstrated that good recovery performances of CRM can be achieved through concentration of high-CRM WEEE.
RecyclingBörse	Production of Nd-Fe-B from magnets Extraction of Tantalum from capacitors	Tantalum Rare Earths (Neodymium)	Germany	• Tantalum recovery by bio-leaching shows a high potential for new innovative research, the achieved leaching rate of about 15% is a relatively high level. • Further applied and interdisciplinary research is recommended, focused on the influence of particle size of input material, bulk densities or better grow conditions. • The main advantages of bio-leaching compared to conventional acid leaching processes are low environmental impact and avoidance of using hazardous substances. • The recovery of Neodymium magnet material by hydrogen decrepitation and melt-spinning results in a fine grain size which is suitable for the production of isotropic hot-pressed and anisotropic hot-deformed magnets. • It is recommended to transform the flakes to isotropic polymer bond magnets. • To produce isotropic polymer bond magnets with improved magnetic properties, the microstructure of the flakes needs to be changed to microcrystalline using annealing under inert atmosphere or vacuum. • High-grade printed circuit boards as well as HDDs are traded in the WEEE sector as specific and individual fractions. This shows a high

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				chance to channelize these mass flows and to become essential sources for Ta and Nd from the WEEE flow.
Asekol	Increasing CRM concentration from WEEE reprocessing	Rare Earths, Platinum Group Metals, Gold, Silver, Copper and Aluminium	Czech Republic	• Output fractions from the treatment line contained low concentrations of CRMs. • Plastic fractions with a particle size <0.5 mm or 0.71-1.5 mm are suitable mainly for recovery of precious metals and copper. Plastic fractions of sizes < 0.5 mm contained higher concentration of precious metals. Their content was increased ~10 times. • For plastic fractions with a particle size of 0.71-1.5 mm, in batch samples from the stationary and the mobile containers the content of Au was increased 9 times with recovery ratio ~ 59 %. Content of Cu was increased 10 times with a recovery ratio ~63 %. More stable results for single elements were reached for samples from the collection yards. Content of Au, Ag and Cu was increased ~ 6times. • Concentration of rare-earth elements in plastic fractions was very low. The trial did not achieve the 300x increase in content required for sale purpose through the methods tested. • Fine ferrous fraction contained the highest concentration ~ 0.13 % of Neodymium. After sieving ~0.6 % of Nd was achieved, which was not enough for sale. To increase content of Nd a subsequent treatment phase is necessary. • To achieve environmental goals and economic recycling of CRMs from treatment line waste, additional treatment is necessary to increase contents of CRMs and new methods for recovery of fine ferrous fractions need to be developed.

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Some of the proof of concept laboratory experiments demonstrated high recovery rates of the materials of interest. The work has for instance shown that bioleaching resulted in high potential recovery rates but lacks commercial viability at this stage. However, considering the significantly reduced environmental impact of bioleaching compared to conventional pyrometallurgical processes, both the real costs and operational risks are lower than those associated with chemical leaching.

The trials highlighted the current challenges of CRM recovery technologies due to the low cost of virgin materials. There is potential to scale-up the recovery technologies that achieved positive outcomes during the trials, where it was demonstrated that the technology worked successfully at a very small scale.

Conclusions regarding the economic and environmental benefits of the laboratory-based recovery trials at a commercial scale could not be confidently drawn; further trials are needed to demonstrate their viability on a larger scale. There is potential to scale-up some of the recovery technologies that achieved positive outcomes during the trials, where it was demonstrated that the technology worked successfully. National and local governments (as well as non-governmental organisations) should partner with R&D projects to encourage the adoption of sustainable methods of CRM recovery such as bioleaching. Furthermore, it is important that the private sector is made aware of the feasibility and benefits of adopting innovative approaches to CRM recovery, versus traditional metal recovery techniques.

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Conclusions

The trials achieved the primary project objective by demonstrating a link between collections methods and effective recovery of critical raw materials. Although the cost and revenues from the individual trials were not directly comparable, they suggested that the collection of high value products (that can be resold with little or no repair) as economically as possible (via a retailer) could offer the most effective means of increasing CRM recovery. Further work should investigate the potential additional costs that could be included (i.e. revenue lost to a retailer from the loss of floor space) and whether economies of scale in both collection and recovery could increase the effectiveness of this method of collection.

In summary, the outcomes from trials highlighted that:

- **Knowledge of what to do is important** – having more information available about where to take waste electricals encourages re-use and recycling.
- **Convenience is also a factor to increase re-use** - using High Street and charity retailers was considered a very **convenient** way to dispose of WEEE.
- **Altruism can drive donations** - most respondents agreed that disposing of their WEEE through takeback schemes was good for the environment.
- **Trust plays an important part in increasing WEEE collections** – consumers reportedly place more trust in High Street brands than charities to handle their data securely.
- **Personal connection matters and increases the economic viability of collections -** there is a link between the collection of high quality/high value products and human interaction at collections points. People are more likely to donate better quality items if they can drop them at a collection point where they have personal interaction with an operative. Relationship helps to build trust, make it more enjoyable and encourage people to recycle by recognizing efforts to do the right thing.
- The trials successfully demonstrated a link between collections and recovery, however to increase CRM recovery **collection mechanisms should be designed with recovery in mind.**
- There is potential to scale-up some of the recovery technologies that achieved positive outcomes during the trials, however investment in R&D is need.

Research findings from the trial also confirmed findings from previous studies:

- Very few respondents had disposed of more than two electronic items in the previous 12 months, and lack of awareness of the correct disposal routes results in the hoarding of WEEE.
- 'Personal' EEEE products including smartphones, tablets and laptops are often hoarded because of their size. These products are easily stored out of sight and are therefore, out of mind.
- Concerns about data security is a factor in the decision to hoard WEEE and there is lack of knowledge regarding the options available for secure disposal of data bearing devices.

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- ‘Personal’ EEE products are more likely to be re-used than discarded, either through resale or passing on to family or friends.
- Children will encourage their parents to recycle hoarded WEEE – pester power works.

There is an argument that collecting greater amounts of WEEE increases the chances that it will be captured, rather than it being hoarded by households or ending up in landfill. However, if ‘recovery’ methods are not considered in the design of collections systems, many of the products that could have been re-used will be too damaged, and CRMs that could have been extracted if they had been sorted and disassembled at an early stage are more likely to be lost due to WEEE shredding. Therefore, the quality of the collection is as important as the quantity that is collected.

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