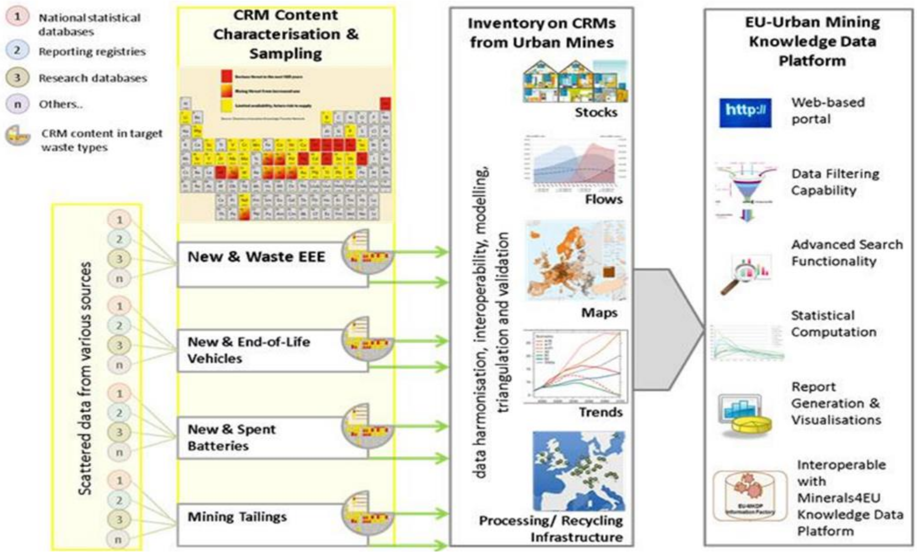
CRM Parameters Characterisation Deliverable 2.1



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Prospecting Secondary raw materials in the Urban mine and Mining wastes

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Notice

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1 PURPOSE AND INTRODUCTION

This Deliverable 2.1, CRM Parameter Characterisations, represents the findings of Task 2.1 to characterise products and components in terms of CRM content, speciation and product residence times including future trends. No new work has been undertaken in this Deliverable but updates are provided where work has been updated since the Deliverable in question was submitted. It is a compact synthesis of three subtasks all of which have their own deliverable reports:

- Task 2.1.1 Screen available data on CRM parameters in products and components (D2.2);
- Task 2.1.2 Identify factors affecting the CRM parameters of products and components (D2.3); and
- Task 2.1.3 Describe trends for future development of CRM parameters in products and components (D2.4).

The research work regarding product and component trends and their composition under WP2 has been one of the most challenging, complex and time-consuming aspects in the ProSUM project. This is due to a lack of data and reports in this field.

The relationship between this task and the other tasks is displayed in Figure 1. More detailed descriptions can be found in the three respective Deliverable reports.

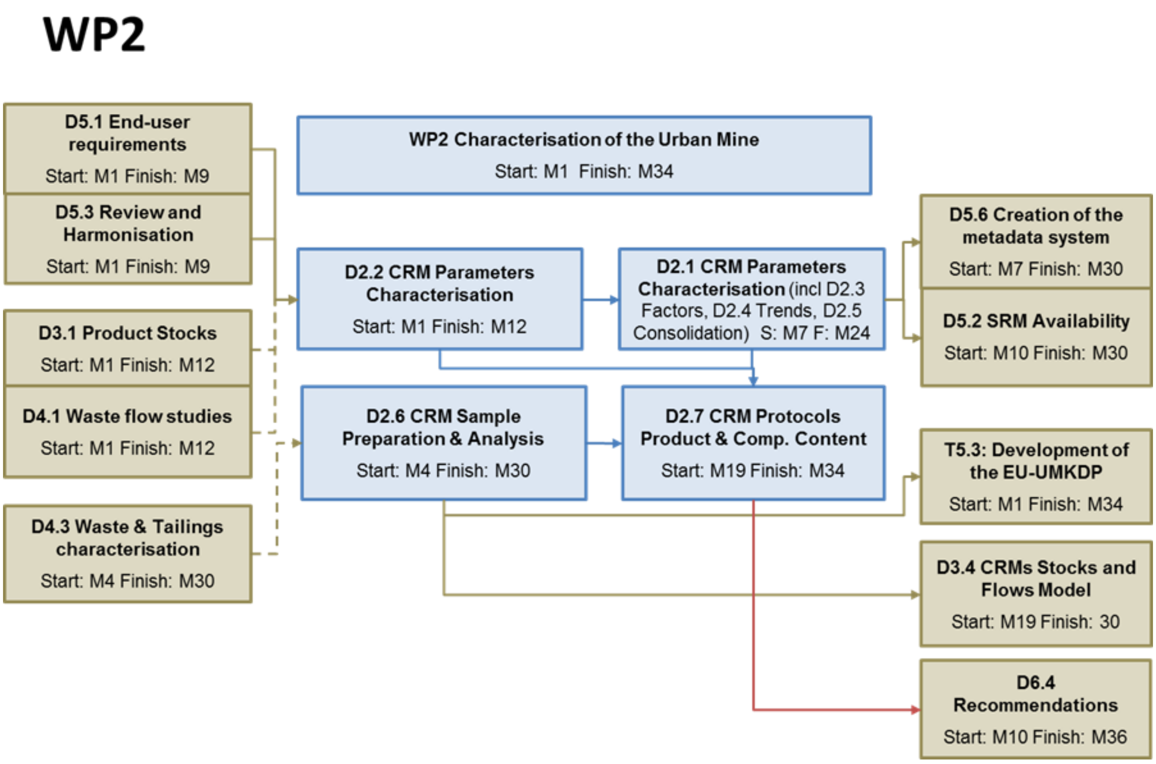

Figure 1: Pert chart for WP2, showing the relationship between D2.1 and other deliverables in ProSUM.

2 Task 2.1.1 Screen available data on CRM parameters in products and components

The outcomes of Task 2.1.1 are described in detail in the corresponding Deliverable 2.2 report submitted in Month 15. Data on CRM parameters were identified in scientific literature and grey literature e.g. industry reports. The general availability of CRM parameter data was found to be moderate, and highly dependent on the type of product, component and element considered.

It was concluded that in general the focus with regards to CRM content is on products and components containing a high weight-% of CRMs. CRM data are usually available at the element level, while bulk materials data are typically at the material level i.e. as alloys. The most commonly studied elements are aluminium, copper, iron, cobalt, neodymium and nickel (see Figure 2). The least commonly studied elements are natural graphite, osmium, iridium and antimony.

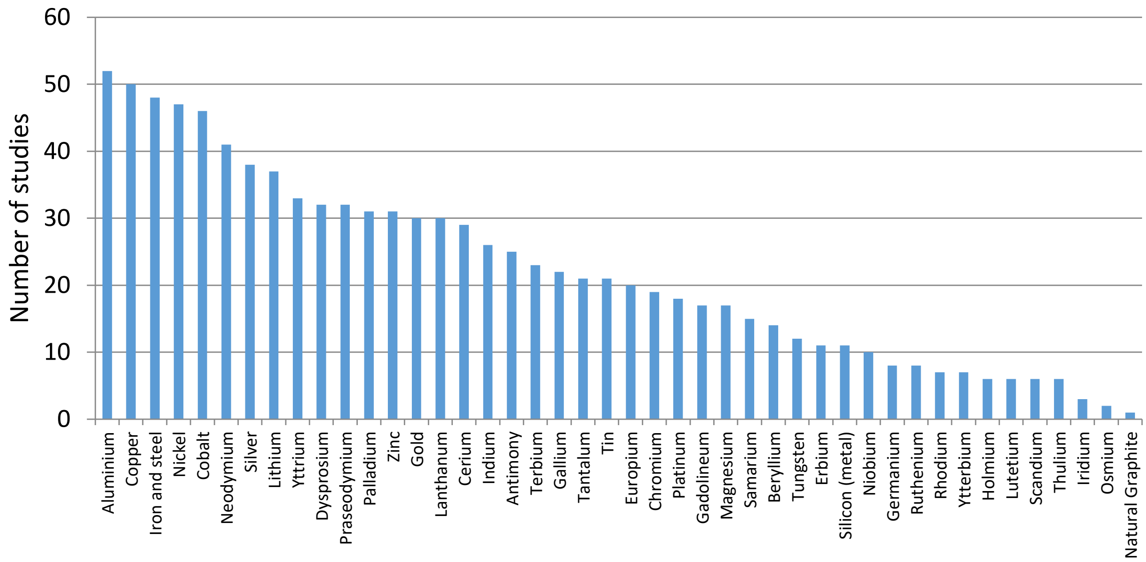

Figure 2: Number of studies included in the ProSUM bibliography addressing the CRMs within the ProSUM scope

The data coverage for products defined in the ProSUM code lists can be characterised as high for batteries (around 50 sources), medium for Electrical and Electronic Equipment (EEE) (around 60 sources), and low to medium for vehicles (around 30 sources). Table 1 shows the occurrence of CRM parameters in data sources for vehicles as an example. Vehicle composition data is dominated by the e-c relationship, menaing that there are richer data sources concerning the composition of components.

Data screened from the literature review have been collated in spreadsheets and databases which ultimately feed into the harvesting templates which will be used to populate the EU-UMKDP. Since the completion of Deliverable 2.2, more data sources have been obtained from unpublished sources and added to the EndNote bibliography and the Deliverable 2.5 vehicle composition data portrayals. (See the Conclusions for an updated total number of sources included in May 2017).

Table 1: Occurrence of CRM Parameters in Data-sources for Vehicles. Green: reference contains data on specified CRM parameter. Red: reference contains no data on specified CRM parameter. See Figure 2 of D2.2 for the e,m,c,p definitions below

Author - Date	e-m	e-c	e-p	m-c	m-p	c-c	c-p
Alonso, E., T. Wallington, A. Sherman, M. Everson et al. (2012)			√				
Cullbrand, K. and O. Magnusson, (2012)			√				
Du, X., R. Widmer, E. Restrepo and P. Wäger (2014)		√	√				
Ducker Worldwide, (2011)				√	√		
Ducker Worldwide, (2012)				√	√		
European Aluminium Association, (2013)					√		
Habib, K., H. Wenzel (2014)		√					
Habib, K., P. K. Schibye, A. P. Vestbo, O. Dall and H. Wenzel (2014)	√	√	√		√	√	√
Jody, B., E. Daniels (2007)		√			√		
Kummer, B., (2014)			√		√		
Labie, R., G. Willems, D. Nelen and K. Van Acker (2015)		√			√	√	
Løvik, A. N., R. Modaresi and D. B. Müller (2014)		√			√		
Ministry of Environment Japan, (2009)		√	√				
Modaresi, R., D. B. Müller (2012)					√		
Sander, K., W. Kaerger, M. Groke, M. Bergamos R. Kohlmeyer (2014)		√	√				
Widmer, R., X. Du, O. Haag, E. Restrepo and P. A. Wager (2015)		√	√				
Zepf, V., (2013)		√				√	

The ProSUM project has defined product categories based on keys, aligned with the UNU keys for WEEE (see Deliverable 5.3). For batteries, most of the defined keys, e.g. battery types, are well covered for composition data. For EEE, there are a large number of studies on the composition of a few specific keys, especially mobile phones, personal computers and TVs, but other defined keys have very little data available. For vehicles the least data has been identified, however, some important variations are covered, such as the difference between conventional, hybrid and electric cars. Inevitably however, available stock and flows information is not configured to easily represent the composition differences. In this case a flexible vehicle classification system was developed in Deliverable 5.3, enabling the linking of compositional data with vehicle fleet and product information.

The lack of CRM parameter data for many product keys and components is the most important issue to address in the continuation of this work. There are at least three possible ways of dealing with this: i) a continued search for data; ii) estimation based on existing data for other product keys and components; or iii) narrowing down the scope, for example by aggregating keys to a higher level. In general, it is expected (based on the experience gained during this ProSUM task) that a combination of the three will be required. The second important issue to deal with is the availability and relevance of data on products or components which are currently not covered by the ProSUM code lists. This could be addressed by expanding the code lists, but it is important to make sure that such expansion also makes sense considering the availability of data on stocks and flows. A third important issue to deal with is the inconsistency between terminology used in literature and the code lists defined within ProSUM. It is sometimes difficult, especially on the material and component level, to accurately describe the references, for example because measurements have been undertaken for a component which were defined differently than in the ProSUM components list. This issue has been tackled in D2.5 where the methodology for data gaps and judgements on data quality are addressed.

The data screening in Task 2.1.1, conducted using an EndNote library (the ProSUM bibliography), is specifically set-up to be able to categorise, filter and manage the continuously growing knowledge base behind the EU-Urban Mine Knowledge Data Platform. It contains 315 references, of which around 120 contain data on CRM parameters at the time also for later Deliverables.

3 Task 2.1.2 Identify factors affecting the CRM parameters of products and components

The outcomes of Task 2.1.2 are described in detail the corresponding Deliverable 2.3 report issued in Month 21.

To identify factors affecting the CRM parameters of products and components, three case studies were utilised where rich data sources were available: permanent magnets in Hard Disk Drives (HDD), permanent magnets in vehicles, and CRM content in batteries over time (1980-2016).

Based upon these case studies, a list of factors posing significant influence on the CRM content within the CRM parameters c-c (mass, mass fraction, number, length, volume, area or other extensive property of a component in another component); c-p (mass, mass fraction, number, length, volume, area or other extensive property of a component in a product); and e-c (mass or mass fraction of an element in a component was identified. These factors were grouped into 3 overarching categories: technological, business and governmental. Societal factors are included in the business and governmental factors.

Table 2: Overview of identified factors in the selected case studies

Keywords in literature indicating a factor	Factor category	Potential underlying reasons	CRM affected	Vehicles (magnets)	Battery	EEE (magnets in HDD)
“due to size” “compact” “shape” “thin” “Ultraportable” “diameter”	Technological - dimensions	Miniaturisation. Customer demand	All CRM	√	√	√
“Power” “Charge / discharge rate”	Technological – power out, higher energy density	Product features Customer demand	Co, La, Sm, Nd, Pr – many CRM	√	√	√
“Weight” “Ultraportable”	Technological - Mass	Product features Customer demand	Co, La, Sm, Nd, Pr – all CRM	√	√	√
“resistance to temperature”	Technological – Temperature	Product features Customer demand	Co, La, Sm, Nd, Pr - all	√	(√)	√
“corrosion”	Technological – chemical and or electrochemical reaction	Product features Customer demand	All CRM	√	√	√
“other devices” “shifts in system”	Technological – system interface with other devices	Product features Customer demand	Co, La, Sm, Nd, Pr - all	√	(√)	√
“economy”	Technological – system power requirements	Product features Customer demand	Co, La, Sm, Nd, Pr - all	√		√
“market” “maturity” “volumes”	Business – market forces	Company internal forces, Forces between companies. Customer demand. Conflict materials, geopolitics and regional instability, insecurity of supply.	All CRM	√	√	√

"Economic requirement"	Business – cost / price forces	Company internal forces, Forces between companies. Market systemic forces. Customer demand	All CRM	√	√	√
"Lifetime" "calendar life"	Business – market forces	Company internal forces, Forces between companies. Market systemic forces. Customer demand	All CRM	√	√	√
"Legislative requirements" "mercury"	Governmental forces – toxic and mining, process and product waste controls	Toxic & hazardous materials, Pollution, waste, eco- protection, shipments of waste, protection of 3rd countries, bio diversity.	Cd, Hg All CRM	√	√	√
"safety" "standards" "vehicle requirements"	Governmental forces – Legislative – product regulations – industry standards	consumer safety protection	All CRM	√	√	√
"R&D spend"	Business – R&D investment. Also Governmental - policy – inter-governmental, defence and fiscal	Sizes of markets, payback periods, business confidence, costs of new technology development, global financial systems, stock markets, banking sector, central bank policy, interest rates, shift in loci of economic power (W to E), Defence spend. global debt.	All CRM	√	√	√

There is a pronounced spectrum of factors that affect CRM parameters of products and components (Vehicles, Batteries and EEE). The technological factors are the most pronounced in the literature, in particular the demand to reduce size and mass whilst increasing performance. These factors are in turn measurable and therefore scientific approaches can be taken to determine qualitative assessment of factors affecting CRMs in the products and components. The main focus of analysis of factors in literature is around the size, mass and performance of product in order to deliver product which will perform well in the market.

Less reported on is the impact of legislation which has significant effects on changes to CRM composition in product such as restricting certain substances e.g. leading to lead-free soldering. The same can be said of extending product life/durability. International disputes, conflicts and embargos can also have a rapid and significant effect on CRM composition in product e.g. Tantalum in capacitors. These are however seen as temporal factors, difficult to define concisely and impossible to predict. It concerns the actions of states and this human factor makes the link with scientific / technological factors difficult to assess. Hence, it has not been possible to weight the above factors quantitatively due to bias encountered concerning the ranking of importance in literature and the impossibility to predict external factors in the future. As a result, Deliverable 2.4 aimed to describe future trends rather qualitatively regarding the nature and drivers behind these. Actual forecasting is primarily based on extrapolating trends using currently available data for the most relevant parameters such as trends in product consumption (per market and key), existing trends in CRM concentrations for the most relevant components, and determining key physical parameters like average product and component weight and size.

4 Task 2.1.3 Describe trends for future development of CRM parameters in products and components

The outcomes of Task 2.1.3 are described in detail in the corresponding Deliverable 2.4 report issued in Month 29.

In view of all trends affecting the CRM parameters of products and components, the aim of D2.4 was to extrapolate the time series developed in Deliverable 2.3, and combine this with the available data and literature from earlier work in the project, to generate insights for expected product and material composition developments.

The following approach was used:

- The ProSUM bibliography (developed for the project) and the data and intelligence it contains were evaluated for relevance;
- Previous work and data were evaluated for inclusion and utilisation; and
- A wider literature search was also conducted concerning trend prediction and analysis undertaken within industry (not included in the bibliography).

The methods and techniques encountered and tested, have been used to develop a framework for predicting and modelling future scenarios for CRM parameters. Work undertaken in Deliverable 2.3 to identify the factors in the trends of CRM parameters in products and components in the short term, was analysed together with data on products POM in the past and resulting in waste flows, and taking into account disruptive technology developments.

A range of product based graphs in the form of curves, adoption curves, S-curves and Gartner's Hype cycle commonly used in product development and marketing to establish sales and market penetration; were then used together with literature on critical materials composition in products, to help develop CRM trends in products.

The findings for EEE, vehicles and batteries show a correlation between the curves and the application of materials which allows for examples of short term trends in CRM parameters, to be presented. The results of this deliverable will be utilised in WP3 to model stocks and flows of CRMs to create the CRM inventory and in the development of future scenarios to assist in the development of services and features for the EU-UMKDP.

Future trends of CRM in WEEE flows

The use of materials for the design and production of electronics in EEE is evolving rapidly over time. Here the key trends are more products becoming 'smarter', smaller and more multifunctional. This in turn is affecting the design and material composition of new products significantly. Due to the dynamic shifts in technology and material use in most EEE products, specific trends and forecasts are difficult to substantiate quantitatively. Nevertheless, it was possible to apply the diffusion curves to the available information taken from literature to analyse trends and establish the link between product and material trends for secondary raw materials present in stocks and flows. As an example, gold present in the Screens category of WEEE generated over time is shown in Figure 3.

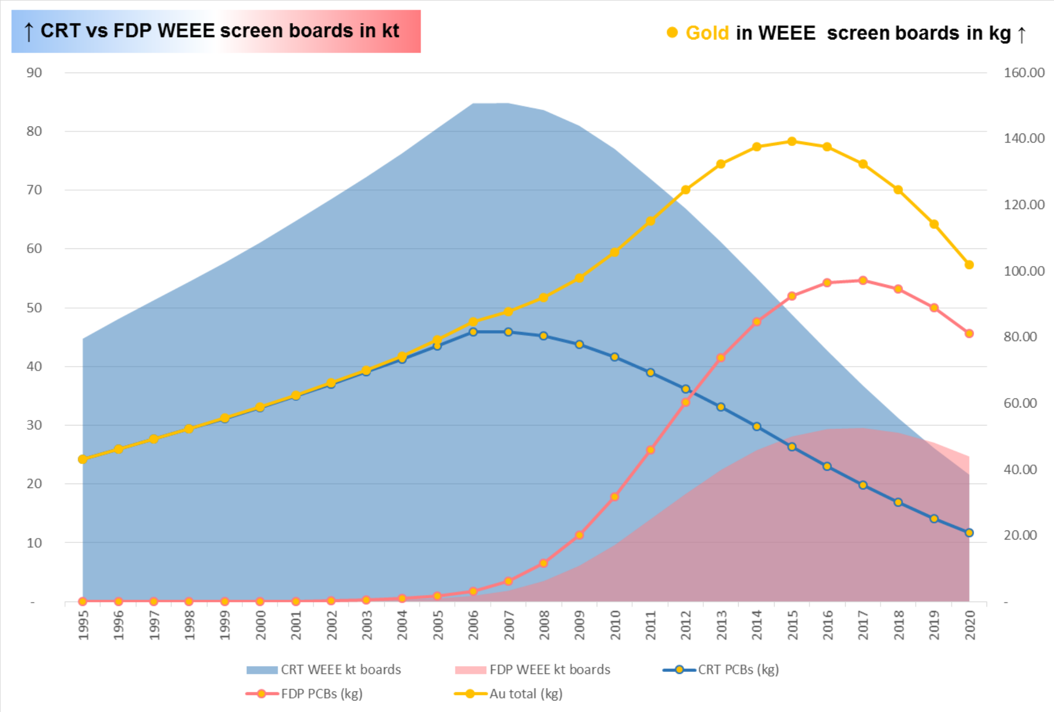

Figure 3: Gold content in printed circuit boards over time

By means of analysing the specific trends in materials, components and products consumption, a summary of all trends in particular for new EEE products has been established for all UNU keys. A more comprehensive qualitative overview of newly appearing, ‘stable replacement products’ and of, sometimes exponentially, disappearing products has been constructed in the form of the so-called UNU key catalogue available in Annex 1 of Deliverable 2.4. Most important for overall project progress is that this work on product and component trends is connected with parallel work in WP3 on stocks and flows and the compositional consolidations made in 2.5, and will lead to the mapping of specific CRMs over time.

Future trends of CRM in End of Life Vehicle flows

Based on observed current and historic trends for fleets and vehicle designs, qualitative conclusions for CRM in generated End of Life Vehicle (ELV) flows at present and in the future can be drawn. Observations regarding ELV flows which may be generated later into the future, are also made based on current intelligence about the future development of the vehicle fleet and car designs. Quantified estimates for the total mass of CRM in vehicle stock and flows are not provided in D2.4. They will be generated as part of upcoming work in ProSUM for Deliverable 3.5 similar to the BATT and EEE research.

Overall, it can be expected that the total mass of the vehicle stock and annually generated ELVs will increase slightly over the coming years. Electrified vehicles will only constitute a small minority of ELVs for a long time. One of the key trends in the vehicle configuration in the past two decades has been the increasing electrification and automation of vehicle functions. Similar to WEEE, many new components are being introduced which is displayed in Figure 4 below.

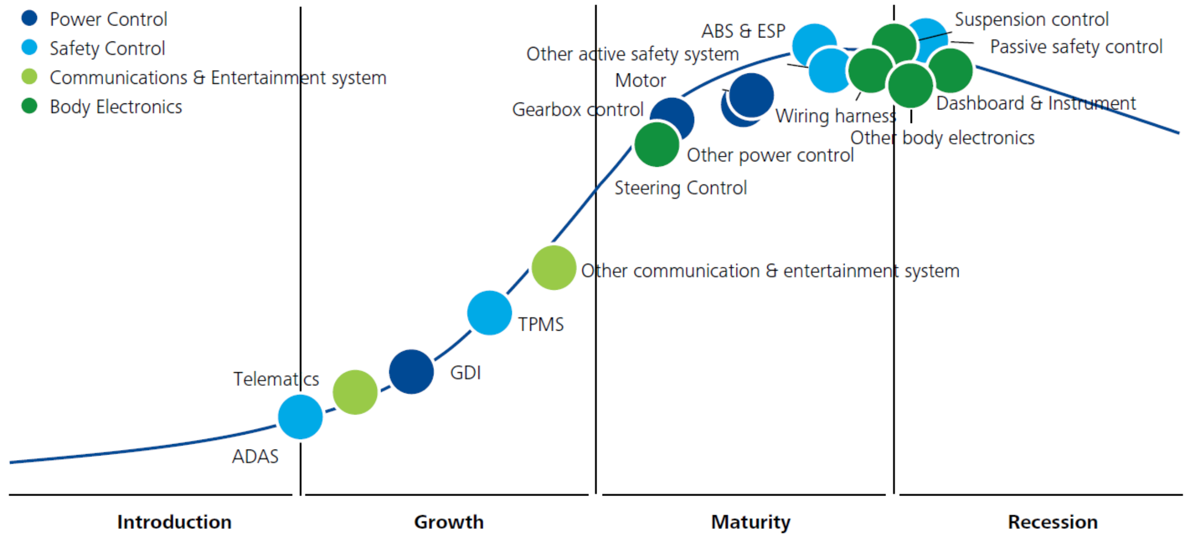

Figure 4: Market penetration of various electronic systems in vehicles (Deloitte China Automotive Practice 2013). ADAS = advanced driver assistance systems, GDI = gasoline direct injection, TPMS = tire pressure monitoring system, ABS = anti-lock braking system, ESP = electronic stability program.

This obviously affects the CRM contents over time significantly. In terms of CRM quantities in the ELV flow, the shift in use of construction materials and steel types for example may have had a relatively small impact, although some increase in niobium and molybdenum is likely. Only a small increase in cast aluminium content is expected in the coming years, as its use in new vehicles has only grown slowly in the past decade. With the rapid increase of wrought aluminium use, magnesium as an alloying element is also increasing. The late introduction of catalytic converters for diesel cars combined with the European diesel boom in the 2000s will lead to a large increase in platinum arising from ELVs in coming years. It is clear that electrical and electronic devices have increased significantly in new vehicles over the last years, which will lead to an increasing occurrence of these devices in ELVs in the future.

Future trends of CRM in BATT flows

The CRM containing components of batteries are typically rare earth elements in NiMH batteries, cobalt in the cathode materials in Lithium Cobalt Oxide (LCO) and Nickel Manganese Cobalt/Nickel Cobalt Aluminium (NMC/NCA), and natural graphite in the anode. NiMH batteries are being replaced by lithium-ion batteries, which is a very heterogeneous group of electrochemical systems using a high variety of material combinations.

The battery market depends on the development of the markets for battery-containing products. Decisions taken by the battery producers in practice relate to the selection of the type of electrochemical that will be used in the product and its material composition. These decisions heavily impact on the consumption of CRM.

As an illustration of the completed work, the forecast of Cobalt generated as waste from electric vehicles is displayed in the next graph.

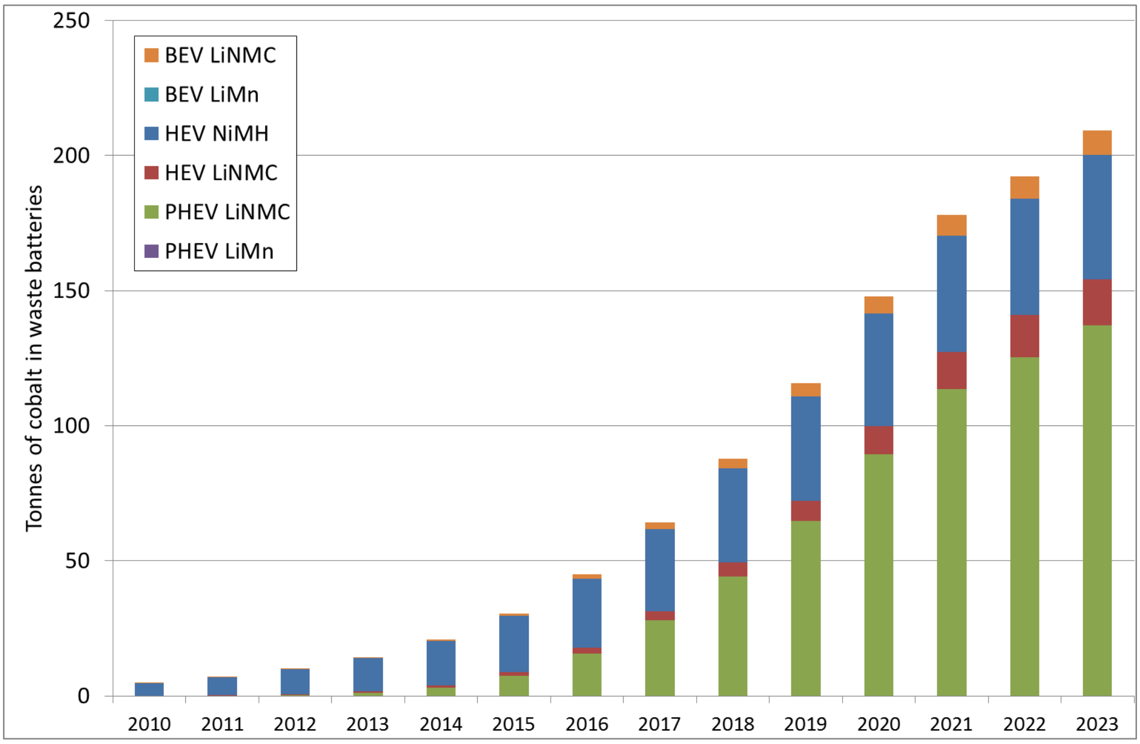

Figure 5: Estimates of the amount of cobalt contained in the generated waste batteries from electric vehicles

The available studies provide quantitative results for future trends for products containing batteries that differ in detail between data sources but agree in terms of general qualitative trends that are:

1. Increased demand for batteries for electric mobility, for instance for BEV and PHEV. Here it is risky to forecast sales volumes after 2025.
2. The demand for batteries for energy storage systems will strongly increase.
3. The market for portable batteries will also increase with rates depending on the products. A diversification in the usage of batteries related to the digitalisation of many products will result in the development of new markets whereas some other markets will decline.

Overall the approach of looking at what is coming onto the market is a good indicator of materials in the urban mine going forward. Whilst this in itself is no surprise, this report highlights that the focus of many who seek to develop an understanding of the urban mine, tend to observe waste flows rather than market and technology trends for product coming on to market. At the same time, those in companies who make choices on which products will be successful in the market place, tend not to consider the impact on materials in the urban mine.

5 Conclusions and Outlook

This Deliverable is a compact synthesis of the subtasks 2.1.1 Screen available data on CRM parameters in products and components (D2.2); Task 2.1.2 Identify factors affecting the CRM parameters of products and components (D2.3); and Task 2.1.3 Describe trends for future development of CRM parameters in products and components (D2.4). It illustrates the analysis which has been undertaken on products, components and materials. The results of this analysis are being utilised in WP3 to create the CRM stock and flows model and to inform future scenarios which will be developed as part of the applications and services under development in WP5 on the EU-UMKDP.

The following key milestones have been achieved:

- A comprehensive characterisation of all studies, literature and other sources in a well specified bibliographic repository that functions well within the project and amongst the research teams in the ProSUM consortium. At the time of writing, the current Endnote library which is constantly updated contains 720 individual sources in total. Of these, 145 unique sources relate to batteries, 104 to vehicles and 224 to EEE, which have all been reviewed, analysed and processed into harmonised formats. (These numbers include more than CRM parameter data e.g. product and flow information).
- In Task 2.1.2 all factors affecting CRM contents have been analysed, forming the framework for the qualitative and quantitative descriptions of product, component and material trends in Task 2.1.3.
- In Task 2.1.3 more extended analysis has been conducted leading to a thorough qualitative understanding of a broad range of trends as well as a quantitative forecasting and back casting of the observed and anticipated product trends for: EEE until 2023, for batteries in EEE until 2020, for BATT in electric vehicles until 2023, and for vehicles until 2025 for the majority of the CRMs.
- The combined research covered by these three Deliverables are already connected with the adjacent work in WP3 on stocks and the compositional consolidations made in D2.5; allowing for mapping of CRMs and products over time..

It is difficult to accurately describe the data available in external sources, especially on the material and component level. However, due to the structured and comprehensive approach taken on defining, classifying and scrutinising all available data, substantial progress is being made in ‘prospecting the urban mine’. The work undertaken in Work Package 2 research is very valuable and will be captured in improved guidelines and protocols for updating and expanding CRM data coverage in the future.

References

All references and detailed descriptions are available in the Deliverables 2.2, 2.3 and 2.4.