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Are scarce metals in cars functionally recycled?

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ABSTRACT

Improved recycling of end-of-life vehicles (ELVs) may serve as an important strategy to address resource security risks related to increased global demand for scarce metals. However, in-depth knowledge of the magnitude and fate of such metals entering ELV recycling is lacking. This paper quantifies input of 25 scarce metals to Swedish ELV recycling, and estimates the extent to which they are recycled to material streams where their metal properties are utilised, i.e. are functionally recycled. Methodologically, scarce metals are mapped to main types of applications within newly produced Swedish car models and subsequently, material flow analysis of ELV waste streams is used as basis for identifying pathways of these applications and assessing whether contained metals are functionally recycled. Results indicate that, of the scarce metals, only platinum may be functionally recycled in its main application. Cobalt, gold, manganese, molybdenum, palladium, rhodium and silver may be functionally recycled depending on application and pathways taken. For remaining 17 metals, functional recycling is absent. Consequently, despite high overall ELV recycling rates of materials in general, there is considerable risk of losing ELV scarce metals to carrier metals, construction materials, backfilling materials and landfills. Given differences in the application of metals and identified pathways, prospects for increasing functional recycling are discussed.

1. Introduction

Current car design trends point at increasing diversity in materials use to meet regulatory, business and consumer requirements on environmental performance, safety, costs, comfort and infotainment (Edwards, 2004; Ghassemieh, 2011; Ljunggren Söderman et al., 2014). While future cars with electrified powertrains may increase demand for specific metals, significant quantities of several metals are already used in today's conventional cars (Alonso et al., 2012c; Ljunggren Söderman et al., 2014). Many of these metals are considered scarce, or 'critical', because of increasing global demand and limited availability due to geological rarity, geopolitical issues and technical or economic constraints on extraction (European Commission, 2010; Skinner, 1979; U.S. Department of Energy, 2010). Consequently, the some one billion cars in use worldwide today (Sakai et al., 2014), constitute a significant secondary resource of scarce metals.

However, current recycling systems for end-of-life-vehicles (ELVs) are mainly focused on securing hazardous content and recovering bulk materials such as steel and aluminium. Recycling targets, such as the 95% target for cars and trucks below 3.5 tonnes specified by the EU ELV directive (European Commission, 2015), are based on vehicle mass and do not specify targets for individual metals. There is thus a clear risk that scarce metals are not returned to material streams where their metal properties are utilised, i.e. that they are not functionally recycled (Graedel et al., 2011; Guinée et al., 1999). Instead, they may be dispersed in recycled residual waste or not be recycled at all, and thereby lost. Furthermore, metal dispersion could downgrade bulk flows with significant environmental impacts (Nakamura et al., 2012).

Developing functional recycling of ELV scarce metals requires knowledge of car metal contents and fates of individual metals in recycling systems. However, publically available information on both is limited. Some studies have focused on individual metals or metal groups such as nickel, chromium and molybdenum applied in steel alloys (Ohno et al., 2014), platinum group metals (PGM) (Alonso et al., 2012a), lithium (Kushnir and Sandén, 2012), and rare earth elements (REE) (Alonso et al., 2012b). Few studies have provided more comprehensive assessments. A review identified six studies related to conventional cars, and observed substantial variations in scarce metal contents (Du et al., 2015). Regarding fates, there are considerable knowledge gaps. Measurements of scarce metals in some waste flows exist for certain metals, such

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as cobalt (Ruffino et al., 2014), and manganese (Edo et al., 2013; Granata et al., 2009; Morselli et al., 2010; Ruffino et al., 2014), in automotive shredder residues. In recent research, scarce metals are measured in selected electrical and electronic car components and in outputs from shredding of complete cars (Widmer et al., 2015), but metals are not traced throughout the recycling system. To our knowledge, there is a lack of system-wide mapping of scarce metals in ELV recycling.

The aim of this study is therefore to answer the following questions: (1) What is the magnitude of scarce metal contents in discarded cars? (2) What are the fates of these metals in the current ELV recycling system? (3) Which fates constitute functional recycling and which risk leading to irreversible losses? Additionally, prospects for increasing functional recycling are discussed. Empirically, the study focuses on the Swedish ELV recycling system and covers 25 metals.

2. Materials and methods

Publicly available data does not allow us to quantify with sufficient precision the scarce metal contents of cars reaching the ELV recycling system, or map individual metal flows within it by means of substance flow analysis (SFA) (van der Voet, 2002). Instead, a three step procedure is used for establishing the order of magnitude of metal flows and assess the extent of functional recycling. First, annual input of scarce metals to the ELV recycling system is estimated by combining the number of discarded vehicles with product information on three recently produced car models. Each scarce metal is allocated to one, two or three *main application categories*. Second, a material flow analysis (MFA) (Brunner and Rechberger, 2004), of ELV waste streams is conducted to identify potential pathways of each category. Third, based on identified pathways, potential fates of each metal are established. Fates are assessed in terms of whether they correspond to functional, non-functional or no recycling. These three steps and data sources are further described in Sections 2.1–2.3, respectively.

2.1. Scarce metal input and applications

The average number of annually reported Swedish ELVs encompassed by the EU ELV directive was slightly less than 190,000 between 1995 and 2012. With a fairly stable vehicle fleet of around four million cars as over the last 20 years (BIL Sweden, 2015a), and an assumed average ELV age of 18 years (BIL Sweden, 2013b), a similar number of ELVs can be expected in 10–20 years. Metal input is calculated on the ELVs reported in 2012, based on passenger cars only because trucks and busses only represent 5% of reported numbers (BIL Sweden, 2013a; Transport Analysis, 2014a), and information on their scarce metal contents is unavailable. Legally or illegally exported cars, long-term garaged or illegally disposed cars are outside the scope of study, as are vehicles excluded from the ELV directive.

Making a full account of the metal contents of ELVs entering Swedish vehicle recycling is unfeasible because car brands in the current running fleet number well above 70 (BIL Sweden, 2015b), the age span of ELVs is roughly 50 years (BIL Sweden, 2014), and publicly available data on metal content is lacking for most brands and models. Instead, estimates of content and applications representing conditions around year 2012, are based on three recently produced diesel-powered Volvo cars manufactured for the Swedish market (Cullbrand and Magnusson, 2012), complemented with other sources (Geological Survey of Sweden, 2014; Ljunggren Söderman and Ingemarsdotter, 2014; Widmer et al., 2015). Car #1 is mid-sized fitted with standard equipment. Car #2 is slightly heavier, a few years older in design and somewhat more equipped. Car #3 is of similar design to car #1, but significantly more equipped than the others (Supplementary material, Table S1). The data set for these model cars originates from the International Material Data System (IMDS) (Cullbrand and Magnusson, 2012), to which auto industry suppliers provide component content data. It includes 19 metals at component level and six metals at vehicle level. The three models are separately used to calculate annual metal input, resulting in input intervals (Fig. 1). Intervals are assumed as fairly representative of ELVs around 2030, since the Swedish market share for Volvo, together with Volkswagen and SAAB with similarly sized cars, was 40% around 2012 (BIL Sweden, 2015b). However, the share of diesel-powered cars was only 20% (Transport Analysis, 2014b), thus metal input stemming from particulate filters is overestimated.

To trace metals through the recycling system, data from model cars are used in constructing seven *main application categories* of scarce metals. In the data, a number of typical components and materials are allocated to individual metals, enabling this categorisation. For reasons of confidentiality, metal quantity is presented at the aggregated vehicle level (Supplementary material, Table S1). Four of the categories are alloys of major metals; steel, aluminium, magnesium and nickel. The remaining three are lubricants, catalytic components (interior of catalytic converter unit) and electric, electronic and magnetic components (Fig. 1).

2.2. Potential pathways of application categories

To identify potential pathways of application categories, a MFA model of the Swedish ELV recycling system is constructed. The model is based on official ELV waste streams statistics, complemented with data on key system processes. Data was sourced from official statistics, reports, waste management literature and qualified experts. Industry association directors or specialists were regarded as experts on activities representative for their industries, i.e. as industry experts. Technical specialists at companies treating large ELV waste shares, were regarded as technical experts. Industry experts provided descriptions, statistics or estimates related to companies or processes of their industries, or identified technical experts. Technical experts provided descriptions or estimates on process details. Five industry and 13 technical experts from five associations and 10 companies were consulted. Open-ended interviews were conducted by phone on 13 occasions, face-to-face on three. E-mail data acquisition occurred five times. Individual statements were cross-checked by querying multiple experts or comparing statements to literature if available. Additionally, experts were consulted for validating data from single literature sources.

The resulting model (Fig. 2), covers six process groups: (A) dismantling, (B) processing of dismantled components and materials, (C) shredding operations, (D) post-shredding operations, (E) energy recovery and slag treatment, and (F) metal refining. Each group is introduced below, with supplementary material Sections S2.1–S2.6 providing detailed information.

(A) Dismantling: Oils, other liquids, components such as catalytic converters, tires, main batteries and window shields are removed from all cars, as required by law. Dismantlers treating relatively new, damaged cars, provided by insurance companies commonly remove spare parts for resale (e.g. gear boxes, engines, doors, fenders and headlights) (Jensen et al., 2012). Dismantlers treating older cars are inclined to remove parts with high aluminium content and sell for material recycling, typically engines, gear boxes, plating and rims (Abraham, 2014; Carlsson, 2014). Recyclable steel is typically generated as a consequence of removing desired components or materials (Supplementary material, Section S2.1).