

The Challenges and Potential for Increasing the Recycling of Post-Consumer Aluminium Scrap in the UK

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Abstract. With the emphasis on circular economy and sustainable development, the demand for the reuse of post-consumer aluminium (Al) scrap is rising. Current recycling processes, such as downgrading and dilution, can lead to the accumulation of contaminants in the resulting alloy and a surplus of non-recyclable scrap. This is not viable for sustainable development of the manufacturing industry, and optimised recycling strategies and systems are required. The existing literature is relatively scattered and lacks a unified integration of related fields. This paper is trying to mitigate the gap by a cohesive synthesis across interconnected domains. It aims to analyse the potential problems and barriers to the upgrading of the aluminium scrap recycling industry in the United Kingdom (UK) and explore feasible solutions from different perspectives. This article reviews the latest literature while also collecting recent information from the industry to analyse the overall development bottlenecks of aluminium recycling and reuse development. These obstacles include a dearth of available data, the complexity of diverse alloy types, mismatches between market supply and demand, and associated recycling costs. It points out potentially effective actions through use cases and provides a framework for improving strategies and future work.

Keywords: Aluminium Recycling; Post-consumer Aluminium Scrap; Sustainable Development.

1 Introduction

1.1 The trend of aluminium scrap surplus

While demand for both primary and secondary aluminium is growing, global aluminium scrap is also increasing, with surpluses in some regions [1]. The amount of recycled aluminium from post-consumer scrap has increased by nearly 70% in 2021 compared to 2009 [2]. However, based on the simulation from Van den Eynde et al. (2022), by 2040, only 84% of all collected and processed aluminium scrap could be used to produce new wrought and cast alloys [3]. Countries like Austria may face a situation where cast and mixed aluminium scrap could exceed the final cast aluminium demand within 20 years [4]. To improve the resource utilisation rate of abundant scrap aluminium, the barriers to aluminium scrap recycling and reuse in industry are worth exploring.

1.2 Scrap metal industry and market in the United Kingdom

Due to the waste management experience from early industrial development and current highly developed recycling technology, the cost of recycling scrap in the UK is relatively not high [5]. In addition, the post-consumer scrap value of aluminium is often high enough to justify the investment in modern waste collection and sorting equipment [6]. As a result, with the help of policies and regulations like collecting garbage tax, the scrap metal industry has become an essential sector in the UK [5]. All metal recyclers must have the correct licence to operate legally which includes the Scrap Metal Dealers Licence and the Waste Carriers licence [7]. To date, there are more than 3,500 scrap metal dealer license holders issued by local authorities [8].

According to an EU report, common key market players include scrap processors, scrap dealers and scrap traders as shown in Fig. 1 [9]. The processors, also often collectors, take actions to increase scrap's value for recycling after collection. Aluminium components can be recovered separately (for example wheels, heat shields and doors) at authorised treatment facilities that mainly process ELV vehicles [9]. The scrap dealers can store the scrap rather than just organising trade logistics as traders [9]. As the main users of aluminium scrap and semi-product producers [9], remelters can produce wrought alloys such as extrusion billets and rolling ingots from clean and sorted wrought alloy scrap, while refiners can use mixed scrap to produce foundry alloys and deoxidised metals [10].

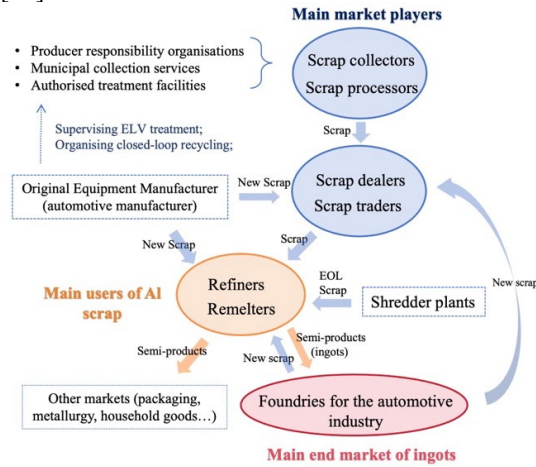


Fig. 1. The main players in the aluminium scrap recycling industry [9]

Although aluminium scrap has been recycled in large quantities domestically since 2004, it is also exported massively due to more lucrative trade [11]. As the 4th largest exporter of scrap aluminium in the world, the UK exported more than 630,000 tonnes of “aluminium waste and scrap” (HS Code: 7602), with \$1.13 billion of scrap aluminium exports in 2022 [12, 13]. The export of metal scrap could lead to the loss of a critical resource that, in the long term, will also affect the semifinished products industry [1]. Chances are that with the surplus of aluminium from end-of-life (EoL) vehicles

the UK can establish new circular supply chains capable of meeting all the domestic manufacturing needs in the future [12].

Based on the urgent need for resource conservation and the large potential for aluminium scrap reuse, this article focuses on the challenges and potential solutions for upgrading the aluminium scrap recycling industry in the UK.

2 Literature review

This article aims to analyse the potential problems and barriers to the upgrading of the aluminium scrap recycling industry in the UK and explore feasible solutions from different perspectives. Due to the lack of integration of previous studies from different disciplines about the topic, qualitative research by reviewing literature and industry reports was evaluated as an appropriate method.

Methodology: First, to support the multi-disciplinary analysis, the related areas were identified as technology, market, and policy. Second, relevant literature in each area was searched and reviewed. Keywords include "aluminium recycling", "post-consumer aluminium scrap", "material flow analysis" and "UK". Third, further screening. By reading the abstract, filter out the literature with high relevance and temporarily exclude the ones with lower priority. More specifically, this study focuses on the transportation sector and the automotive industry, as the surplus of aluminium scrap is sensitive to trends in the automotive industry, especially due to the increasing use of aluminium in light vehicles [1, 3]. The transport sector may become the largest consumer of aluminium semi-finished products by 2030 [14]. In addition, the scope of this paper does not include environmental impact assessment and specific scrap processing technologies. Finally, the results of the study were summarised and a multi-disciplinary framework for future work was generated.

2.1 Lack of data or lack of access to data

Material Flow Analysis (MFA) is commonly used to estimate the throughput of materials in a sector, region or nation, which can provide a prerequisite for creating a sustainable industrial ecology [11]. Based on decades of industry data, expert knowledge, and literature views, there already have been global and even regional aluminium flow models published to quantify stocks and flows of aluminium alloys across space and over time and evaluate the potential to recycle aluminium scrap [15]. Provided that some data of the system is frequently missing or limited, the aluminium scrap flows could be potentially determined based on the material flow model based on the mass balance equations of the material flow model. Buchner et al. [16] successfully simulated the old aluminium scrap flows from different end-of-life applications and processing routes in waste management even though there was nearly no open access data on the generation of old waste and national collections. Cullen & Allwood [17] revealed a complete map of global flows of aluminium from liquid metal to final products for the first time by MFA.

However, it seems hard to find an open-access database on aluminium flow in the UK within a few years. In the first literature using material flow analyses for iron, steel

and aluminium flow in the UK, Davis [11] mentioned that the production and consumption data from some trade bodies and the Office of National Statistics did not meet the requirements for MFA at that time. These requirements nowadays may become even higher when the model further considers the different lifespans of EoL products. Based on the methodology and modelling of the MFA for the UK from Davis, Dahlström and Ekins [18] further consider the economic dimensions of those material flows, pointing out the high value of available post-consumer aluminium scrap through a value chain analysis.

Unfortunately, after this, there was a time gap in the open-access literature on aluminium streams in the UK, although there is some literature about the MFA of aluminium worldwide or in the EU [3, 17, 19, 20]. Studies on the quality of aluminium scrap are even rare probably due to the diversity of alloy composition, lack of uniform evaluation criteria and difficulty of sampling. This is not a problem only for the UK. The researchers from Austria mentioned that little information on the quality of imported and exported scrap is reported in any statistics [4]. Such an opaque market may bring barriers to the aluminium recycling study.

Stakeholder willingness to share data may be one reason. For example, refiners that handle multiple types of scrap and work with several scrap suppliers may have extensive databases of the historical composition of scrap. These databases can be seen as part of their know-how and expertise, giving them a unique edge [9]. In such cases, accessing such databases can be challenging for outsiders.

2.2 The diversity of alloy types and mixed scrap composition

As various alloys with different properties are used in different industries, the post-consumer Al scrap collected at a given point in time can be very heterogeneous due to the uncertainty of the source of scrap, different lifetimes of the products, and the wide variety of alloy compositions. Besides, as products become more complex aluminium components are more densely connected to other materials, which means the scrap is more likely to be contaminated with external elements such as steel, copper or zamak [9]. The alloying elements are hard to remove due to the nature of aluminium to absorb foreign elements [10].

Moreover, considering the growing demand for more advanced aluminium alloys in the automotive industry, there might be a quality mismatch between the scrap supply side and the demand side [21]. Facing this gap, “downcycling” is the current common solution – using cleaner scrap streams to produce lower-purity products [22]. The quality and properties of the Al alloy are reduced and altered compared to the original Al alloys when recycled in this way [23]. Due to the limited sorting, lack of market incentives and the large demand for cast alloys, most collected aluminium scrap is “downcycled” to produce cast aluminium alloys which have a higher tolerance to alloying elements and impurities [3]. In 2012, there was more than 6 Mt wrought scrap globally downcycled to cast alloys [24]. This may lead to further scarcity of high-quality scrap with less impurity in the market.

According to the optimisation model from Zhu & Cooper [25] even though all EoL aluminium scrap can be collected in the United States, only about 70% can be recycled

domestically due to the composition mismatch between the scrap and the target new alloy. If the existing recycling system is not upgraded or redesigned, scrap surplus will be difficult to avoid due to this mismatch. Raabe et al. [24] thoroughly introduced the effects of scrap-related impurities in different cast and wrought alloys and challenges in aluminium alloy recycling procedures and technologies. They also concluded that future work might include the development of more scrap-compatible engineering alloys with greater tolerances of certain tramp, as well as the reduction of alloy chemical complexity to achieve more consistent properties [24].

2.3 Immature domestic market and insufficient production capacity

The domestic post-consumer Al scrap market is still developing. Secondary refiners are facing challenges in their trading due to the rapidly changing prices of Al scrap and primary metals, as well as volatility in the foundry alloy market [26]. Scrap imports and exports help ease pressure on the domestic market and balance the quality and supply of scrap between countries, but it will increase dependence on foreign markets. Besides, given the profit-seeking nature, many market players may opt for low-risk and low-cost chances, not necessarily recycling. Leirag & Tveit [27] noted that recycled aluminium could cost approximately 2.5% more.

To increase domestic Al scrap recycling and reuse, in addition to the challenges faced by the downstream consumer, another issue to consider is whether there is sufficient production capacity of secondary aluminium to support this industrial transition. The Aluminium Federation reports that the arising of aluminium scrap far meets the needs of the UK foundry industry [26]. Although numerous, most collected scrap cannot be processed and consumed domestically. This is partly due to the UK having insufficient facilities to process the full volume of recovered materials [12].

3 From literature to a conceptual framework for research

3.1 Technology development

With the aim of high-value Al scrap supply, classification and sorting technologies are essential to avoid cross-contamination of different types of scrap [11]. Scrap sorting carried out for end-of-life vehicles can mitigate the generation of unrecyclable scrap and reduce the primary aluminium requirement by 15–25% [20].

X-ray Transmission (XRT) measurement is currently used to separate Al-Cu and Al-Zn alloys from other aluminium alloys, and Laser-induced Breakdown Spectroscopy (LIBS) can determine the composition of the aluminium parts during the sorting process [24]. The mixed scrap is sometimes sorted into alloy groups to produce the desired alloy with minimum reprocessing, as different alloy groups have different concentrations and tolerances for alloying elements and impurities [3, 11]. The study divided 275 samples into five categories related to their alloy type through the X-ray Fluorescence (XRF) measurement, including the 1000 series, 3000 series, 5000/6000 series, cast alloy and other wrought [3]. Although various sorting technologies show promise, each must demonstrate added value to achieve widespread deployment [28].

Another potential classification strategy is to separate wrought and cast to establish a “wrought-to-wrought” recycling system [3]. The difference in composition between the most popular series of wrought alloys is even much smaller than that between general wrought alloys and cast alloys [3]. The cast alloys have more complicated element compositions and are also normally cheaper than wrought alloys, so given the high value of wrought and sensitivity to impurity, “wrought-to-wrought” recycling can help to avoid wrought alloys downcycling and prevent mixed scrap from exceeding final cast Al demand [4, 12].

Besides, good design in disassembly and joining technology can avoid the impurity entering the recycling process at the source. The control limits for the impurity Fe were found to determine the scrap utilisation in the production of automotive aluminium extrusion [29], however, some of the Fe impurities in the Al stream come from mechanical fasteners made of steel [30]. These impurities are highly affected by the design of the material structure, the size of the joints used, and the efficiency of the recycling process in sorting small to fine particles [30].

Developing scrap-compatible alloys is also a promising area of research. It can boost post-consumer scrap demand by accommodating more scrap during the manufacturing process. Zhan et al. [29] have demonstrated that AA6082 aluminium extrusions can be produced with more than 70% post-consumer scrap, and they have some performances comparable to the baseline extrusions made of primary aluminium.

3.2 Market and supply chain improvement

While technological advancements can help meet the demand for high-quality scrap and increase scrap reuse in compatible alloys, transformational changes in business models and supply chains are also crucial for the scrap recycling industry. These changes would enhance resource integration and support the adoption of new industrial ecosystems.

With the aim of a robust and comprehensive supply chain of post-consumer scrap, it is worth encouraging to enhance real collaboration between players in different stages of the value chain, creating an ecosystem to develop R&D, reduce trade barriers and work on common goals [14]. For example, an effective LIBS sorting system has been developed by Austin AI with a large British recycler to recover aluminium 6063 from construction and demolition (C&D) materials [31]. Daaboul et al. [32] developed a practical reverse logistics network for recycled aluminium used in high-end structural components, considering the distinct roles and responsibilities of participants in gate-keeping, collection, sorting, and recovery processes. The term ‘high quality’ for customers often simply refers to more specific and well-defined scrap grades [33]. It has been proved that if EoL vehicle scrap can be deployed as a direct secondary material source, it can be used directly to produce alloys with properties comparable to those of common automotive sheet alloys, such as good rolling properties, yield strength and elongation [34].

Meanwhile, adequate data needs to be collected over time. It will not only support policymaking and help businesses make better investment decisions, but it will also benefit market transparency and academic research such as MFA. Performing MFA for

alloy elements and contaminants in aluminium in the UK will provide a prerequisite for designing an appropriate scrap sorting system for aluminium scrap [11]. A reliable database of scrap compositions can help pre-select scrap streams for targeted Al component production [29].

3.3 Policy incentives

To support the transformation to the green materials industry, policies could be implemented to address the negative externalities associated with aluminium scrap recycling. For example, faced with the fact that there is insufficient capability and market support to process recycled materials, investment in increasing infrastructures around sorting scrap feedstock might be helpful [12]. In addition, the research funding will play an important role in innovative sorting technologies (x-ray, laser, robot, etc.) since there is little economic incentive to invest in more advanced scrap sorting systems widely or to use advanced technologies more widely in industry [6, 35].

Various policy incentives such as carbon pricing schemes, subsidies and mandated change can also benefit the scrap recycling industry. Carbon taxes, Emissions Trading Systems (ETs), and carbon credit mechanisms can be directly linked to the greenhouse gas emissions generated by a particular product or activity. Emerging as a potential tool, Carbon Border Adjustment Mechanism (CBAM) can put a fair price on carbon emissions for carbon-intensive goods that enter the country and encourage cleaner production. Using recycled aluminium can reduce 95% of the emissions associated with the production of metal [36]. When the prices of ETs are increasing to effectively shift the trend from high to low-carbon product imports [37], given the low carbon emissions advantage of recycled Al materials, carbon pricing can help green recycled materials become more competitive [27, 38].

3.4 A unified framework for research

To enable multidisciplinary research and development of solutions related to recycling and reuse, the authors seek to convert existing literature findings into a unified framework to guide the next research steps. In Fig. 2, the authors propose that market conditions and technological developments can be guided by an appropriate set of policies that could influence the coordination or organisation of this complex recycling system as it stands. The transformation of low-carbon industries can be facilitated by technological development, business innovation, and market optimisation. This framework can further help researchers identify appropriate multi-disciplinary tools that can help optimise the system towards higher recycling and reuse rates.

4 Summary

Although post-consumer aluminium scrap has been recycled in large quantities across the country, the UK, as the world's fourth-largest exporter of aluminium scrap, also exports massively. There are some ongoing challenges within the domestic aluminium scrap recycling industry including a lack of available data resources, the

complexity of diverse alloy types, mismatches between market supply and demand, and the associated recycling costs.

Addressing these obstacles requires a concerted effort. The framework for future work in different areas is proposed by the authors based on the above challenges. Greater potential for improving Al scrap recycling can be achieved through close co-operation and mutual reinforcement of technology, market, and policy. Adequate data collection is critical for effective policy development, industry development and academic research. It will also increase market transparency, resulting in more efficient trading. The implementation of instructive policies can invigorate the market, fostering advancements in trading practices and technology development. Particularly, carbon pricing can be a potential tool to benefit the aluminium scrap market by making recycled low-carbon green products more competitive. The research and development of sorting technologies, scrap-compatible alloys and other advanced technologies are the key forces to increase scrap aluminium recycling and reuse.

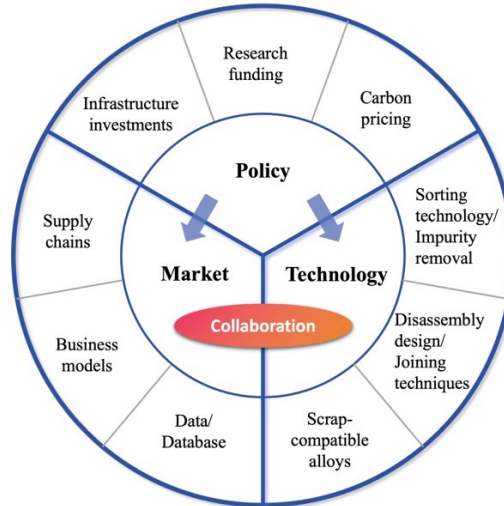


Fig. 2. The framework of potential future work

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