SELECTED MATERIAL STOCKS AND FLOWS -
THE CASE OF ALUMINIUM

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Abstract

Recycling of metals is promoted as an effective way to address resource scarcity, mitigate environmental impacts and reduce energy demand associated with metal production and use. Furthermore, unaltered characteristics of metals after recycling are considered to be a guarantee for an unlimited number of recycling loops and thus suggest metals as ideal recycling materials.

In the present chapter, the potentials and limitations of Aluminium recycling are highlighted using the example of Austria. Based on elaborate material flow analyses it is shown that a significant amount of Aluminium is still accumulating in Austria´s material stock, thereby indicating that even in highly developed economies, metals stocks are growing at a significant rate. With regard to a circular economy, this finding implies that even 100% recycling of Al containing waste & scrap generated may at best only partly cover the Al demand. Due to some saturation of metal stocks predicted for the coming decades, metal self-supply via scrap will increase. Input of primary Aluminium, however, is not only required due to quantitative disparities between Al demand and scrap supply, but might also result from qualitative constraints. The latter is a consequence of changing Al applications over time and thus different Al alloys demanded and arising as scrap. In addition, qualitative constraints might be increased by the absence of alloy specific sorting of Al scrap (e.g. joint recovery of cast and wrought alloys from EOL vehicles). At present qualitative constraints on Al recycling are avoided through the global trade of scrap. For instance, the European Union, which imports significant quantities of primary aluminium, represents a net exporter of Al scrap. Higher domestic added value of metal and Al scrap might be generated if advanced sorting technologies are applied allowing for the generation of high quality (alloy specific) scrap, which might be better utilized by European smelters and thus would help to retain the added value of secondary raw materials within regional cycles.

Introduction

Since Aluminium and its alloys exhibit unique material properties in various aspects (lightweight, flexibility, corrosion resistance, conductibility) it is the second-most widely used metal after iron. Besides increasing use in building applications, Al is a promising material for breaking the weight spiral of cars and is thus increasingly utilized in the automotive sector. In spite of substantial savings in the use phase (e.g. lower fuel consumption of vehicles due to reduced weight), high emissions (fluorides, perfluorocarbons, polyaromatic hydrocarbons, sulphur dioxide and carbon dioxide) and severe environmental impacts of primary Al production (e.g. red mud) must be taken into consideration. In contrast, production of secondary aluminium (utilizing Al scrap) causes significantly lower emissions, generates by far less waste and requires only about 10% of the energy needed for primary production. Thus, with regard to reducing energy consumption and emissions, facilitating Al recycling would be an adequate approach, keeping in mind, however, that the percentage of secondary Al is limited by the ratio of available scrap and total Al demand (Rombach, 2013). Nevertheless, companies in regions with restricted access to primary resources and strict environmental regulations (i.e., the European Union) already depend on the use of Al scrap to a large extent. However, against the background of current resource policies, such as those of the European Union, which state that more efficient use of minerals and metals is crucial for heading towards a sustainable circular economy (COM/2015/0614 Circular Economy Package), the share of secondary metals (including Al scrap) in the production process should further increase in the future.

The present article tries to answer the question to which extent current and future Al demand might be covered by the Al scrap generated. Thereto Austria was chosen as a case study for investigating current and future Al flows and stocks using the method of Material Flow Analysis (Brunner & Rechberger, 2004). Whereas production and trade of Al largely depend on the industries present and are hence very country specific, consumption patterns and final usage of Al in Austria is comparable to many other countries of similar socio-economic development. Hence, the results presented can be regarded as representative for large parts of the European Union.

Present Aluminium Balance and Recycling Rates

The spatial boundary of the analysis is the geographical border of Austria, and the balance has been established for the year 2010. Only metallic Al flows are considered, ignoring elemental Al contained in many other chemical compounds (e.g., industrial minerals such as kaolinite). In the established material flow model, the Al lifecycle is illustrated using five main stages, namely, *production/processing*, *manufacturing/trade of semis*, *trade of Al-containing goods*, "*in-use" phase*, and *waste management*. A detailed description of the analysis conducted and the data sources utilized is given in Buchner et al. (2014).

Figure 1 summarizes the Austrian aluminium budget for 2010. The total production of secondary aluminium amounted to 68 kg/cap/yr with a total input of aluminium scrap of 44 kg/cap/yr. 14 kg/cap/yr of the scrap utilized was internal scrap and the biggest share of the scrap input to Austrian Al smelters and refiners was imported.

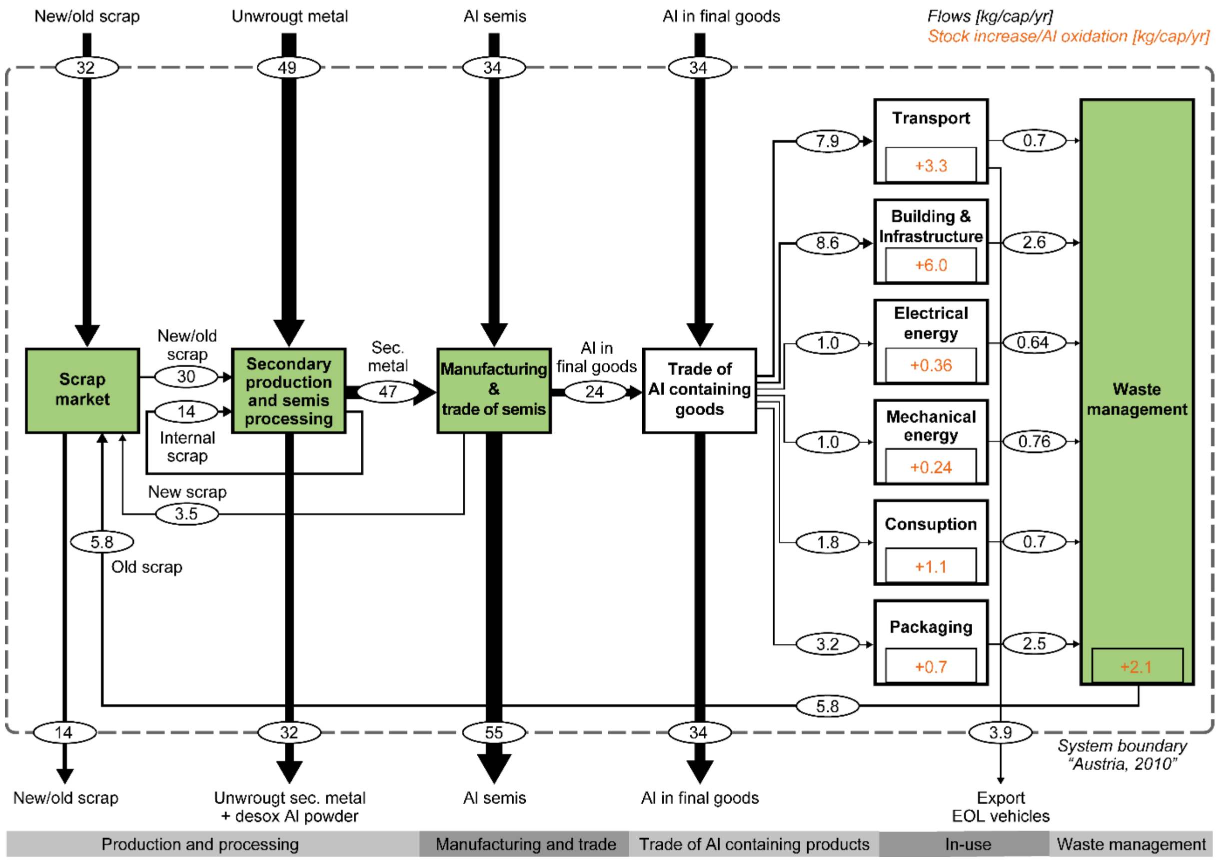

Figure 1 **Aggregated Austrian Aluminium balance for the year 2010. Values given in kg/cap/yr (based on Buchner et al., 2014)**

With respect to manufacturing and trade of Al semis and Al containing products, a total Al amount of 24 kg/cap/yr was domestically "consumed" in Austria and thus entered the "use-phase". The sectors Transport (7.9 kg/cap/yr) and Building & Infrastructure (8.6 kg/cap/yr) exhibit the highest Al inputs, followed by Packaging, which consumed about 3.2 kg/cap/yr in 2010.

Comparing Al use in the different sectors with data on scrap generation and the export of EOL vehicles allowed the annual increase of the Al stock in the in-use phase to be estimated, which amounted to 12 kg/cap/yr. The largest increase was due to the accumulation of Al in buildings and infrastructure (+6 kg/cap/yr).

The output of the in-use phase comprises old scrap, which amounted to about 8 kg/cap/yr, and Al in EOL vehicles, which were exported (3.9 kg/cap/yr). Hence, in total 8 kg/cap/yr of old scrap are potentially available for the Austrian Al industry. Due to losses in waste management (e.g., oxidation of Al during thermal waste treatment, landfilling of Al containing wastes, Al residues present in ferrous metal scrap) about 6 kg/cap/yr of old scrap were finally recycled. Hence, the overall recycling rate of Aluminium in Austria (referred to old scrap generation) amounted to almost 75%. However, with respect to final Al demand (demand of in-use) this old scrap covered only 25% of the consumption (6 kg/cap/yr versus 24 kg/cap/yr). In the case that the exports of EOL vehicles are terminated and vehicles are domestically recycled, this ratio might increase to almost 40%.

Even if a theoretical 100% recycling of old scrap could be established, old scrap would cover at maximum 50% of the domestic Al demand simply due to the fact that a significant share of current consumption is contributing to a net stock increase of Aluminium and thus is not available for recycling at present. All in all the current Austrian per capita stock of Al is estimated to be approximately 350 kg/cap, with an annual growth rate of more than 3% (12 kg/cap/yr).

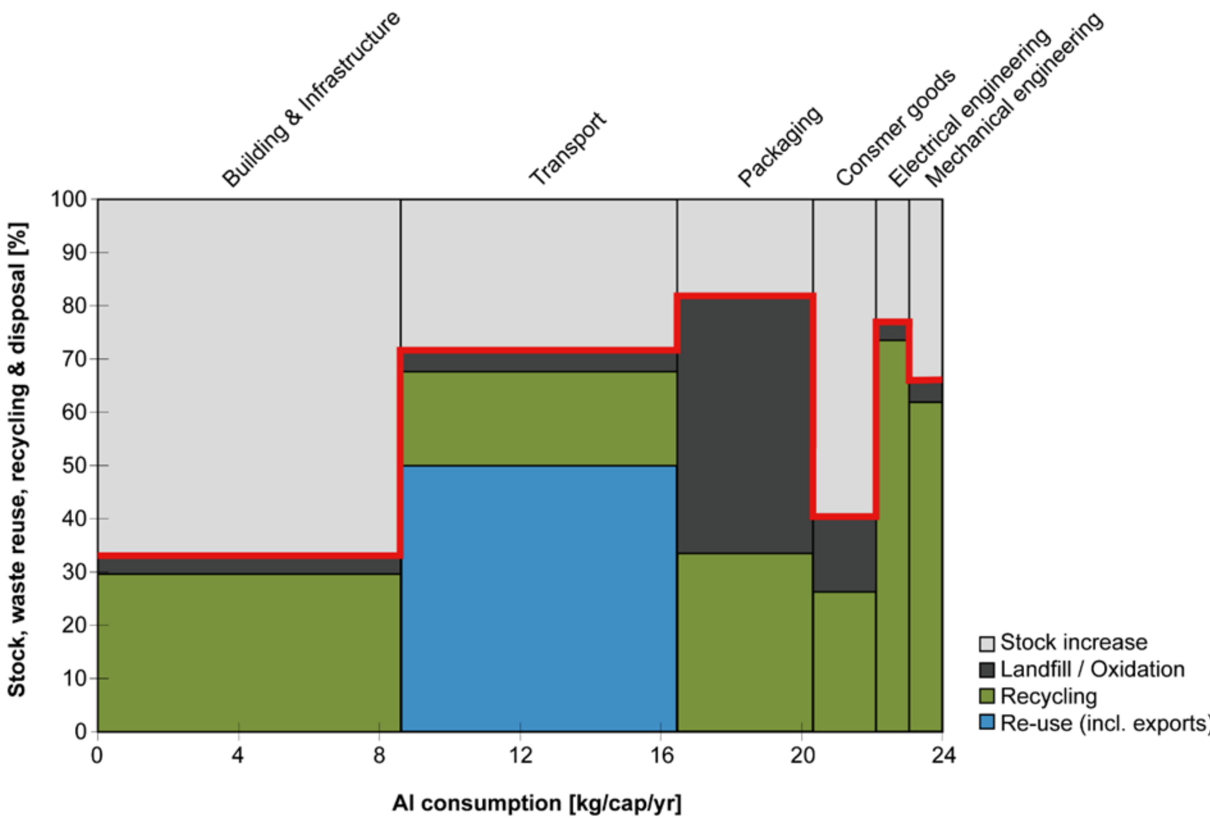

Figure 2 **Management of Al in different end use sectors in Austria for year 2010 (red line indicates the share of waste generation referred to the consumption of Al in the different sectors)**

Future Aluminium Stocks and Flows

As about 50% of the annual domestic Al demand accumulates in the stock and is thus at present not available for recycling, how old scrap generation fed by the Al in-use stock will develop in future and whether a higher self-supply via Al scrap might be accomplished has been investigated. Thereto a dynamic material flow model accounting for historical and future Al demand in the different sectors as well as the respective life time of Al products in these sectors has been established (Buchner et al., 2015a).

The results of this model, which in addition to a prognosis of future Al scrap generation and Al stocks also include a historical analysis of stocks and scrap generation, are given in Figure 3. The total Al in-use stock is likely to increase by almost 50% (to more than 500 kg/cap/yr) until 2050 in comparison to present levels (largely driven by a more intensive use of Al in the transport sector). During the same period old scrap quantities are predicted to double to 24 kg/cap/yr (including Al in EOL vehicles). As the increase in old scrap generation is more pronounced than the increase in total in-use stock (1.5 times by 2050), it may be concluded that, on the one hand, an increasing amount of metal will be released from current in-use stocks and, on the other, that average growth in final consumption is expected to fall below historical values, indicating some saturation of Al stocks in future.

These conclusions of the model are also reflected by an increasing self-supply with old scrap in future. Assuming enhanced recycling technologies (recycling rate of 90% for Al scrap from all sectors) and no export of EOL vehicles, domestic old scrap may cover up to 75% of Austria´s final Aluminum consumption in 2050 (see Figure 3c).

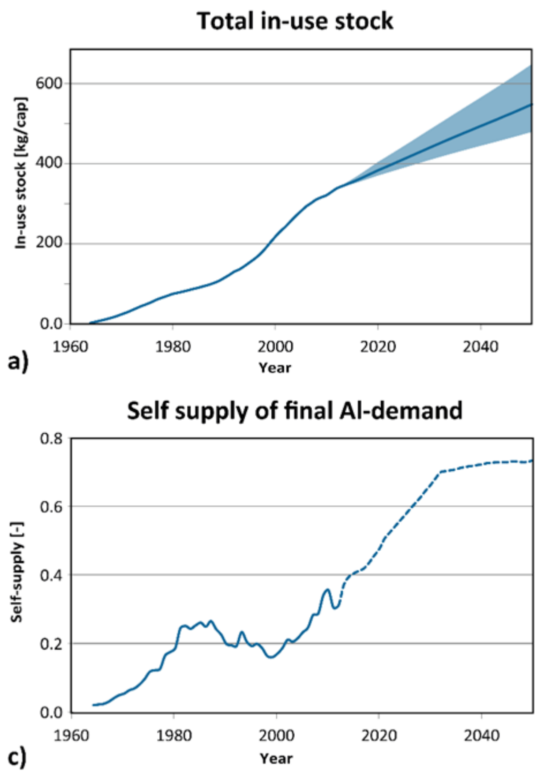

Figure 3 **Development of total Al stock (a), past and future Al scrap generation (b), and self-supply of final Al demand via old scrap (Buchner et al., 2015b)**

Qualitative Issues of Metal Recycling

The predicted rate of self-supply, which is, however, solely based on a quantitative comparison between demand for Al and scrap supply, neglects quality constraints on Al recycling. Al alloys demanded, on the one hand, and alloys or mixtures of alloys generated as scrap, on the other, may not necessarily coincide. In a subsequent analysis (Buchner et al., submitted) the dynamic material flow model has been extended in order to account for the qualitative aspects of Al recycling. In particular, two types of Al alloys, namely cast and wrought alloys, have been distinguished.

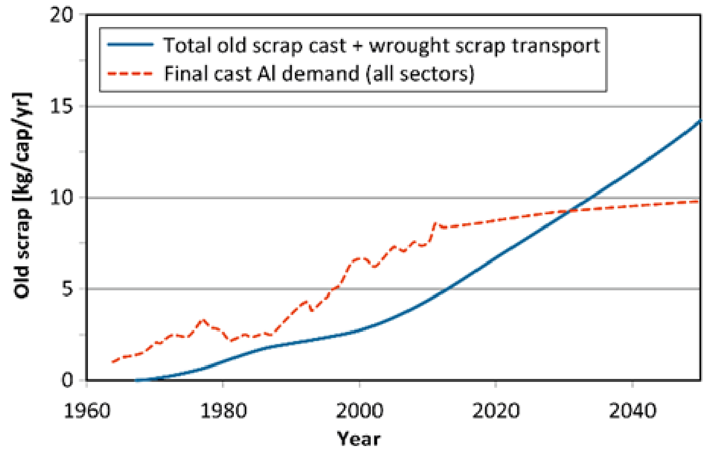

Figure 4Comparison of cast & mixed Al scrap generation with total final cast Al demand in Austria assuming that EOL vehicles are recycled domestically and not exported (Buchner et al., submitted) The modelled trends of old scrap generation (Figure 4) indicate that under the given recycling practice (no sorting of Al scrap) a "closed" system (no export of scrap) would in future (around 2030) generate excess quantities of cast and mixed Al scrap compared to final cast Al demand, which is in line with results for the global vehicle market (Modaresi and Müller 2012). Hence, the contribution of metal recycling to meet overall metal demand might not only be limited by the fact that scrap flows are smaller in quantity than metal demand, but also due to qualitative constraints. Foreign scrap trade, however, balances quality issues between different countries or even on a global scale. Evidence for this statement is provided by figures concerning scrap imports and exports of the European Union. Although the EU is relatively poor in mineral resources, and thus heavily dependent on the import of metal ores or primary metals, the export of metal scrap significantly surpasses imports of scrap. This observation of net exports also applies for other recyclables such as plastics or paper (see Table 1), and is most likely explained by quality constraints on scrap and recyclables.

Table 1 Annual final consumption, waste generation, recycling and net export of different commodities for the EU-28 (Fellner et al., submitted)

	commodities consumed	waste/old scrap		
		generated	recycled within EU	exported for recycling
	kg/capita/yr			
Iron & Steel	290	140 - 160	100 - 110	15 - 20
Aluminium	21	11 - 13	7 - 8	2
Plastics	95	50 - 55	8 - 9	6 - 7
Paper & Board	150	142 - 147	94	16

Figures are based on reports of the respective European associations (e.g. Plastics Europe, CEPI, European Aluminium, Eurofer) and Eurostat

Closed material loops as intended by the Circular Economy Package will require defined secondary raw material fractions and therefore sophisticated but also cost-efficient sorting technologies in order to meet current and future requirements in secondary production. Therefore, processing (in terms of alloy sorting) of old scrap can be regarded as one key factor in order to further increase scrap utilization in Europe and retain secondary raw materials within regional cycles.

Conclusions:

Based on the results of the case study, the following conclusions can be drawn

► Metal stocks (even in affluent countries) are still growing at a significant rate, meaning that even a 100% recycling of scrap may only partly cover metal demand

► Primary metal input is not only required due to quantitative disparities between Al demand and scrap supply, but also results from qualitative constraints (alloy demand vs. alloy supply via scrap)

► Qualitative constraints for metal recycling are currently avoided through the global trade of scrap (the EU represents a net exporter of metal scrap)

► Alloy specific sorting of scrap may reduce qualitative recycling constraints and may lead to a higher domestic added value of metal scrap

► There are significant losses of aluminium (>40%) in some consumption sectors

Recommendations:

► Implementation/advancement of alloy specific sorting of scrap

► Advancement of product design and declaration of product recyclability as a means to enhancing the circular economy of metals

References

Brunner P.H., Rechberger H. 2004. Practical handbook of material flow analysis Florida USA.CRC Press LCC.

Buchner, H., Laner, D., Rechberger, H., Fellner, J., 2014. In-depth analysis of aluminium flows in Austria as a basis to increase resource efficiency. Resources, Conservation and Recycling 93, 112-123.

Buchner, H., Laner, D., Rechberger, H., Fellner, J., 2015a. Dynamic Material Flow Modeling: An Effort to Calibrate and Validate Aluminium Stocks and Flows in Austria. Environmental Science & Technology 49, 5546-5554.

Buchner, H., Laner, D., Rechberger H., Fellner J. 2015b. Future raw material supply, opportunities and limits of aluminium recycling in Austria. Journal of Sustainable Metallurgy 1(4): 253-262.

Buchner, H., Laner, D., Rechberger, H., Fellner, J. (2017). Potential recycling constraints due to future supply and demand of wrought and cast Al scrap – A closed system perspective on Austria. Resources, Conservation and Recycling 122: 135–142.

European Commission (EC) 2015. Closing the loop: An EU action plan for the circular economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2015) 614/2.

Fellner, J., Lederer, J., Scharff, C., Laner, D. (submitted) Present potentials and limitations of a circular economy with respect to primary raw material demand. Journal of Industrial Ecology.

Modaresi, R., Müller, D. B. 2012. The Role of Automobiles for the Future of Aluminium Recycling. Environmental Science & Technology 46(16): 8587-8594.

Rombach, G., 2013. Raw material supply by aluminium recycling – Efficiency evaluation and long-term availability. Acta Materialia 61, 1012-1020.