Future potential and limits of aluminium recycling

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Abstract

The continuously growing importance of the recycling of metals, especially of aluminium as part of the raw material supply is indisputable. Nevertheless there are factors like the impurity level and metal content of secondary raw materials, the multiplicity of alloys, and the increasing amount of composite materials which can limit recycling activities to a certain degree. Further questions result from future development of recycling rates, metal losses during production, manufacturing and use of the materials and their impact on the entire mass flow of primary and recycled aluminium.

This article focuses on recycling potentials of aluminium in Germany concerning the availability and quality of scrap or other secondary raw materials, technological development of material processing and remelting and the efficiency of complete recycling concepts now and in future.

In the same way the limits of aluminium recycling are discussed, depending on scrap condition and availability and technology as well as on quality and ecological aspects. The results can help to identify for example a minimum energy demand at increasing recycling rates of certain secondary raw materials.

1. Introduction

The topics of discussion about the burdens of production and use of metals are changing. Currently sustainable development is the main subject following life cycle (impact) assessment, eco-auditing, precautionary environmental protection and design for environment. In all these concepts of modern life cycle management recycling plays a substantial role mainly due to following facts:

- The atomic structure of metals ensures their unrestricted recyclability
- Recycling is an important part of the raw material supply
- The saving of energy by re-using the metals content can achieve 95%

The recycled contents of non-ferrous metal production in table 1 clarify the high importance of the recycling for the metal supply of the semi-finished product manufacturers and the foundries. Products of lead and copper have with 51 and 39 % a high recycled content. On the other hand aluminium and zinc show lower values due to their electro-chemically less precious character. The high value for lead results from the application in batteries, where the metal is concentrated and easy accessible for recycling. The values shown are to be interpreted only as order of magnitude, since their calculation are not made uniformly. This aspect is described later.

Table 1: Recycled content of metal production (values in %) [1, 2, 3]

	1990	1995	1997	
	World			Germany
Al	23	26	32	37
Cu	41	42	39	51
Zn	23	27	31	49
Pb	46	48	51	50

The values of the recycled contents in the range of 30 to 50 % point out beside high growth rates in the application of the metals also a large potential for the use of secondary raw materials. If metallic products are returned into the material flow after their use and new alloys are produced out of them, the resulting recycling quotas reach significant higher values of 50 – 95 %. The quota describes thereby the relation of the metal quantity produced during the entire recycling process to the metal quantity available in the end of life product.

2. Availability of secondary raw materials

2.1 Definition of recycling terms

With an exact analysis of the existing metal flow and the used technologies one states the fact that a further problem of the recycling exist in the right use of the recycling terms and thus in the description and evaluation of recycling activities. This article introduces technical-metallurgically based solutions.

The overall recycling quota of metals can be described by the collection quota and the technical recycling quota. This separation clarifies the different levels of the recycling and permits a resource oriented view [4, 5].

- The collection quota CQ is thereby the quantity of available secondary material, which are gathered by collection systems, related to the used product quantity.

$$CQ = \frac{\text{collected quantity}}{\text{used product quantity}} \cdot 100\%$$

- Technical recycling quota RQt: Here the quantity of material is determined, which is actually available for utilisation as secondary metal, i.e. it concerns the yield of the technical process.

$$RQ_t = \frac{\text{amount of remelted aluminium}}{\text{amount of secondary aluminium collected}} \cdot 100\%$$

The technical recycling quota consists of two sections, firstly the processing quota, which indicates, how much metallic aluminium from the collection is supplied for melting, and secondly the smelting yield, which indicates, how much aluminium is won as liquid metal, i.e. herein the losses in the resulting salt cake or dross is considered, see figure 1. Together the recycling quotas from collection, material processing and remelting result in the resource-oriented recycling quota (RQr).

In contrast to the recycling quota the recycled content is the share of secondary metal, which is used for processing. It is usually smaller than the recycling quota because with rising application more primary metal must be produced than it corresponds to the losses during the use phase.

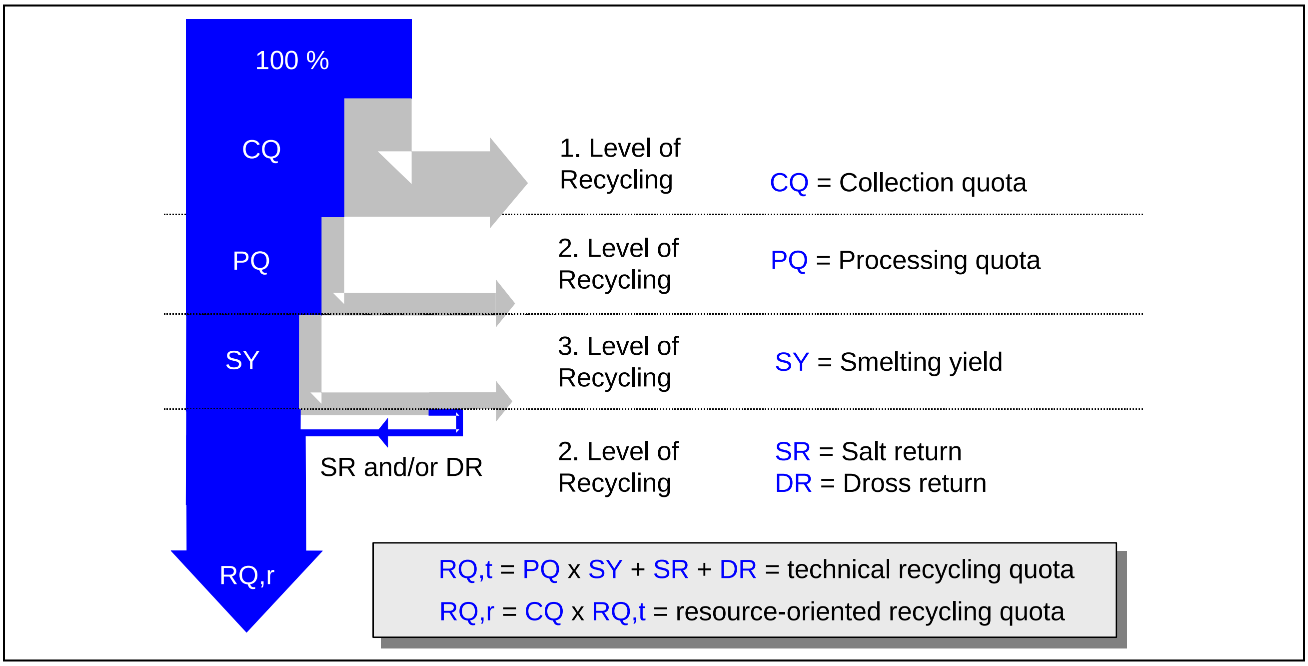

Figure 1: Definition of recycling quotas for collection, processing and smelting [5]

2.2 Current situation

The supply of metal production with secondary raw materials is influenced by various parameters. These are in particular aspects of time and quality, which limit the availability of secondary material.

The difference between the produced and used aluminium quantity in Germany is substantial, like it is shown in the metal statistics, so that the question arises, how is the high metal requirement of the processing industry covered and which role does recycling play thereby. According to figure 2 the recycled content of production would amount to only 18 %, whereby only the secondary aluminium production on cast alloy base is related to the entire metal supply of semi-finished wrought products and castings [1]. This leads undisputed to wrong conclusions.

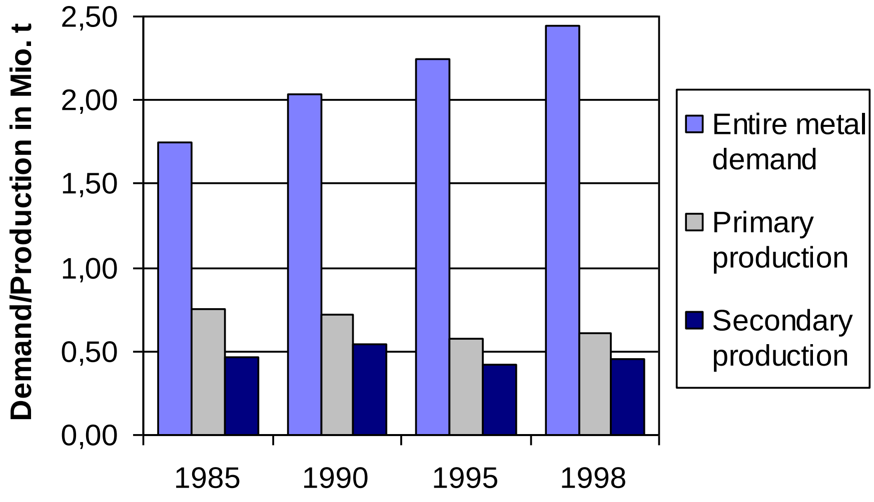

Figure 2: Development of entire metal demand, primary and secondary production of aluminium in Germany [1]

For a precise assessment of recycling activities a qualitative and quantitative description of scrap flows from the areas of application of aluminium is important, as well as their connection to existing recycling paths. Additionally, aluminium materials have to be distinguished in two groups of alloys. For cast alloys the content of alloying elements, first of all silicon and copper, is high. In contrast, wrought alloys are lower alloyed, usually with magnesium and manganese and should therefore return separately and if possible clean sorted into the recycling cycle.

The material separation however is limited by application and collection. Figure 3 shows the German applications of aluminium differentiated by casting and wrought alloys, which is dominated by the traffic sector [6]. In each of these application areas, with exception of the packaging area, casting and wrought alloys are gathered after the use, which are often mixed.

Looking on individual areas of application a further distinction must be made: On the one hand closed loop recycling exist, if scraps are supplied to a comparable reapplication, e.g. beverage cans and window frames. Open loop recycling is present, if secondary raw materials after remelting are supplied to another use usually in form of other alloys. Here in particular the secondary smelters (refiner) are mentioned, which produce cast alloys for the automobile industry for example from a mixture of different old and new scraps.

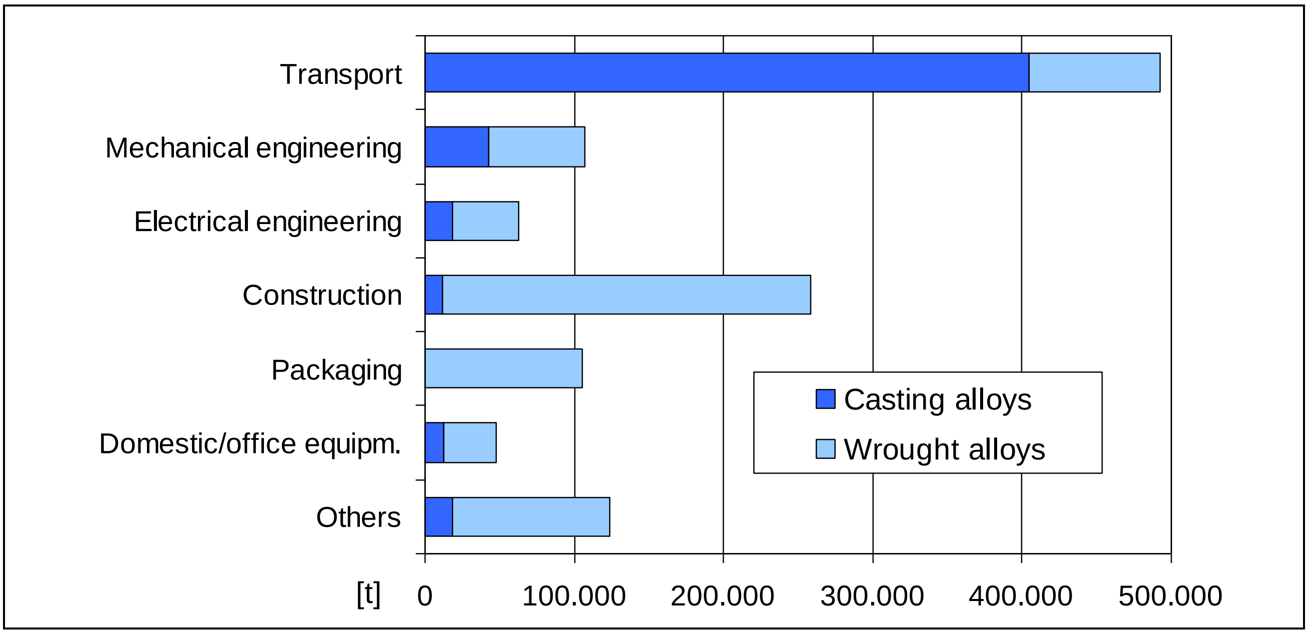

Figure 3: Use of aluminium casting and - wrought alloys in Germany 1997 [6]

Beside this "idealised" statuses an overlap in material and spatial regard exists. Materially, since also wrought alloys are converted to cast alloys, receiving so a material specific modification. Spatially, since production scraps are not only internally used in the plant, but also externally and thus do not remain in a closed cycle. Pure sorted wrought alloy scraps are selectively reprocessed into rolling and extrusion ingots by the remelting plants (remelter), which dispense then both into closed and into open recycling cycles. Mixed and contaminated scraps are reprocessed exclusively into cast alloys by the secondary smelters (refiner) and attain usually into open recycling cycles [7].

During product use the metal is bound in material storage or depots. The entire depot quantity for aluminium is world-wide estimated on 700 Mio. tonnes. The distribution of the metal is spatially, materially and temporally pronounced. The depot characteristics of aluminium can be described on the basis of selected products, product groups or sections or types of use (table 2). For aluminium packaging for example a high spatial distribution exists with small product size and high dissipation at the same time. The material purity can thereby be highly (menu plate, beverage can), middle (cover caps, painted foils) or small (tetrapack, vaporised chip bags). The dwell is with an average lifetime of a half year comparatively small [8].

Table 2: Depot characteristics of aluminium products in selected application sectors [8].

Depot characteristics		**Packa-ging**	**Transport** train/plane	car	**Con-struction**	**General engineering**	**Electrical engineering**
spatially	size	small	high	middle	high	middle	middle
	distribution	high	small	high	middle	middle	high
materially	purity	varied	high	small	high	middle	varied
temporally	dwell	small	high	middle	high	high	varied

The temporal aspect is pointed out in the presentation of production periods, lifetime, recycling quotas, return material quantities of aluminium scraps and the resulting difference to the present requirement in different applications in figure 4.

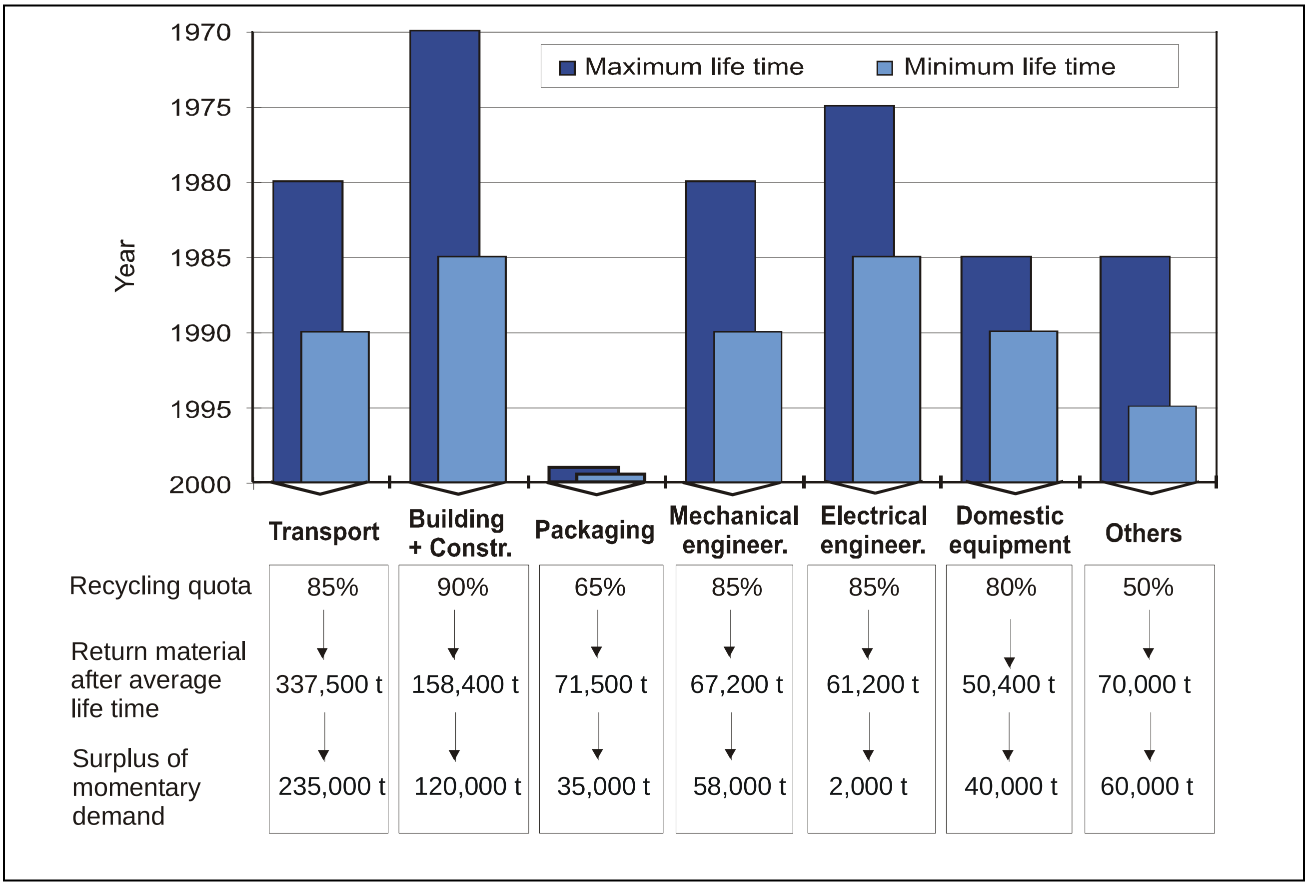

Figure 4: Recycling quotas and return quantities resulting from different lifetimes for different applications under the assumption of complete collection

Today for example scraps from mechanical engineering return, which were produced between 1978 and 1995, thus having a lifetime of 10 to 20 years. Only the mentioned packaging materials return after a short use period in the secondary cycle. By the temporal shift of arising scrap in relation to production the difference between scrap quantity and metal demand becomes larger due to the high growth rates in the aluminium application.

The determination of the arising scrap amount is based on the depot quantities for individual applications and their recycling quotas. The recycled content, i.e. the share of secondary material of products, resulting from this estimation would amount to 60 % for a complete collection of the scraps.

2.3 Quality influence of secondary raw materials on the recycling

Beside the availability the quality of the raw material, i.e. their condition and especially their alloy composition is of high importance for recycling.

Refining of aluminium is possible only constricted and accompanying elements such as iron, manganese, silicon, magnesium, copper and zinc remain predominantly dissolved in the metal phase (table 3). For this reason during primary aluminium production the refining takes place already before reduction. For recycling this means an exact separation of the scraps before melting with regard to type of alloy and purity. Afterwards only diluting with primary metal or blending of different scraps and melts remain as possibility for the alloy adjustment.

Table 3: Possible melt treatment of aluminium

Refining method	**Effect**
Use of melting salt	Removal of oxides
Chlorination	Removal of alkalia and earth alkalia
Gas treatment	Removal of H, Li, Na, Mg, Ca, Sr, oxides, carbides and nitrides
Salt refining	Removal of Li, Na, Ca, Sr and oxides
Vacuum distillation	Removal of Li, Zn, Mg, Na
Formation and separation of intermetallics compounds	Removal of Fe, Mn, Si
Addition of primary aluminium	Dilution of accompanying elements
Addition of alloys	Blending, dilution of single accompanying elements

As consequence from the alloy separation in practice two furnace types became generally accepted. Sort-pure scraps and new scraps are usually remelted in large volume open-hearth furnaces, mixed new and old scraps, dross and turnings in smaller, flexible salt bath rotary furnaces. Despite increasing return quantities from production and use the intensified sort-pure recycling of wrought alloy scraps at the remelting plants causes a lack of blend material at the secondary smelters. So their cost situation continues to get worse due to the then necessary increased demand of primary metal. Accordingly, the scrap input of the German secondary aluminium smelters (figure 5) shows a decreasing share of new scrap in the years 1975-1999, while the share of old scrap developes in opposite direction [9].

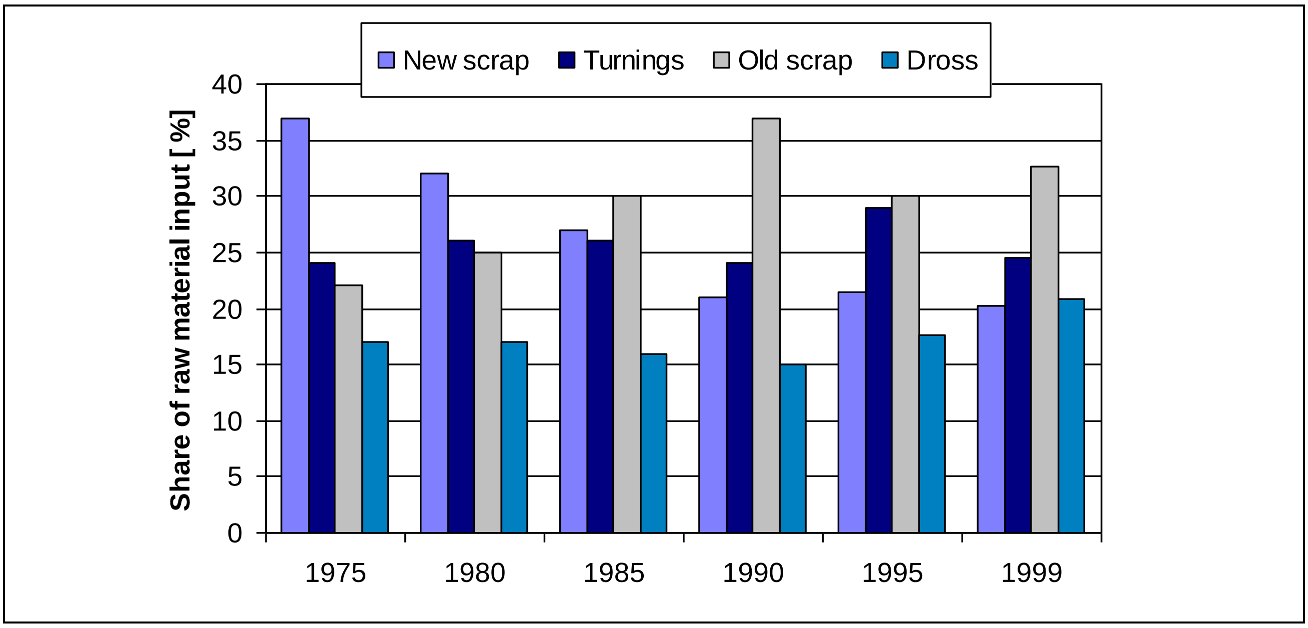

Figure 5: Development of the scrap supply of the German secondary aluminium smelters from 1975 to 1999 [9]

2.4 Quotas of collection and recycling in Germany

With the example of the German packaging recycling the different recycling levels and their corresponding quotas can be explained. In the year 1997 the consumption of light packaging material (LPM) consisting of plastics, tinplate, combined materials and aluminium, amounted to 1,778,198 t, [5]. 1,582,596 t of the used packaging were collected, which corresponds to a collection quota of 89 %. In the sorting plants plastics, tinplate and combined materials are segregated and an aluminium fraction (LPM Al40) is supplied to the further utilisation in the three processes mechanical processing, combined material processing and pyrolysis. The appropriate recycling quotas are shown in table 4. The technical recycling quota reaches 68.4 % and the resource-oriented one 61.7 %.

For the other fields of application of aluminium the quotas are vary significantly [5]. The span of the collection quota reaches from approx. 25 % for aluminium content of the urban waste to almost 100 % of the scrap quantity from the building sector. Therefore the collection becomes the most important parameter for the success of a recycling concept due to the possible utilisation of secondary raw materials.

Considering the collection of secondary raw materials in figure 4 accordingly, the theoretical recycling part decreases from 60 to 46 %. Thus the recycling quota defines the regained metal content of the used materials or components.

Table 4: Technical and resource-oriented recycling quotas for aluminium products [5] *incl. exports

	LPM (DSD)	Building + construction scrap	End of life vehicles	Electronic scrap	Urban waste
Collection quota	89	98	40	84	24
Technical recycling quota	68	92	76	79	12
Total recycling quota	60	90	30	66	3

For the example of aluminium the scrap balance of 1997 in figure 6 clarifies the aspects of scrap availability. First of all a small export surplus can be detected, which consists of old scraps, processing scraps and turnings. For the secondary aluminium production about 400,000 t scrap (Al-content) were used, from which about 70,000 t wrought alloys were remelted separately. Further wrought alloys were remelted in the cast houses of the primary smelters (174,900 t) and the semi-finished product plants (190,000 t) [10, 11]. The amount of production scrap of 920,000 t is directly re-used in the semi-finished product manufacturing as cycle material and is not recorded statistically.

With regard to the shown scrap use, the imported quantity of 168,000 t secondary aluminium and the scrap portion of the foreign primary metal the actual recycled content of total German production results in 37 %. This is a mass-related average value of the individual areas of application.

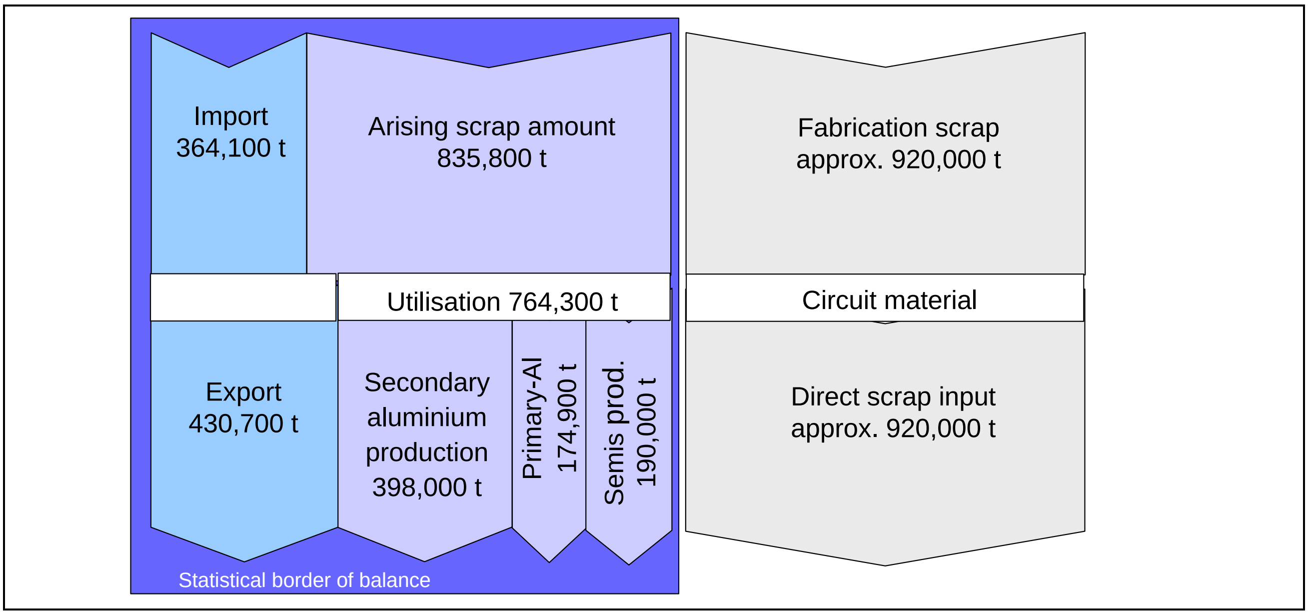

Figure 6: German scrap balance 1997 [10, 11]

2.5 Scrap flows in the aluminium system

It has been shown that the recycled content is unsuitable as scale of valuation for the success of a recycling concept, because it represents a regional situation, which is often strongly falsified by the existing open scrap market and the rising metal requirement in application.

Due to this reason the interaction between the product systems have to be considered. They can be quantified by the existing scrap flows (figure 7). An alloy cascade results, where the recycling activities increase the alloy content of the entire depot. Unalloyed aluminium forms the starting point of this material flow and has therefore the smallest recycling part. Lowering of the alloy status, i.e. a reversal of the usual supplying direction of figure 7 is only possible with high expenditures comparable to the primary metal production.

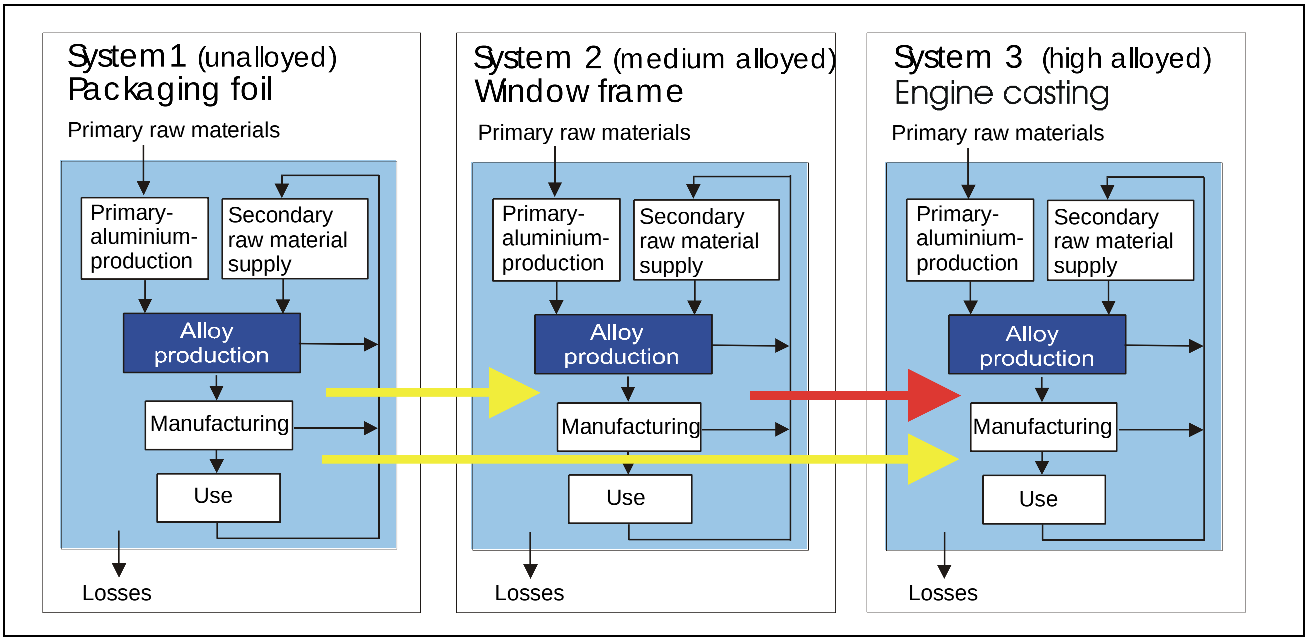

Figure 7: Interaction between the recycling systems

Finally the success of recycling activities can only be measured by the amount of recovered metal and thus the saving of primary metal in the total system of aluminium. It has to be considered that aluminium recycling needs only about 10 % of the energy requirement of the primary smelting. Beyond that the pure sorted collection and material processing work against an enrichment of alloying elements in the recycling cycle and thus receive the maximal utilisation of the secondary raw materials, which are already expensive due to shortage.

3. Technical development

For the example of aluminium packaging potentials of technological development particularly resulting from interactions of processing and smelting can be clarified. Figure 8 shows the existing system of the light packaging recycling. The aluminium fraction from the sorting plants, with 40 %

aluminium content and predominantly organic remainder can not be directly remelted. By the combination of mechanical and thermal processing routes it is possible to obtain a high-quality fraction with about 99 % aluminium which can be remelted with a metal yield of over 90 %. However, the overall processing quota of 73.4 % is relatively low.

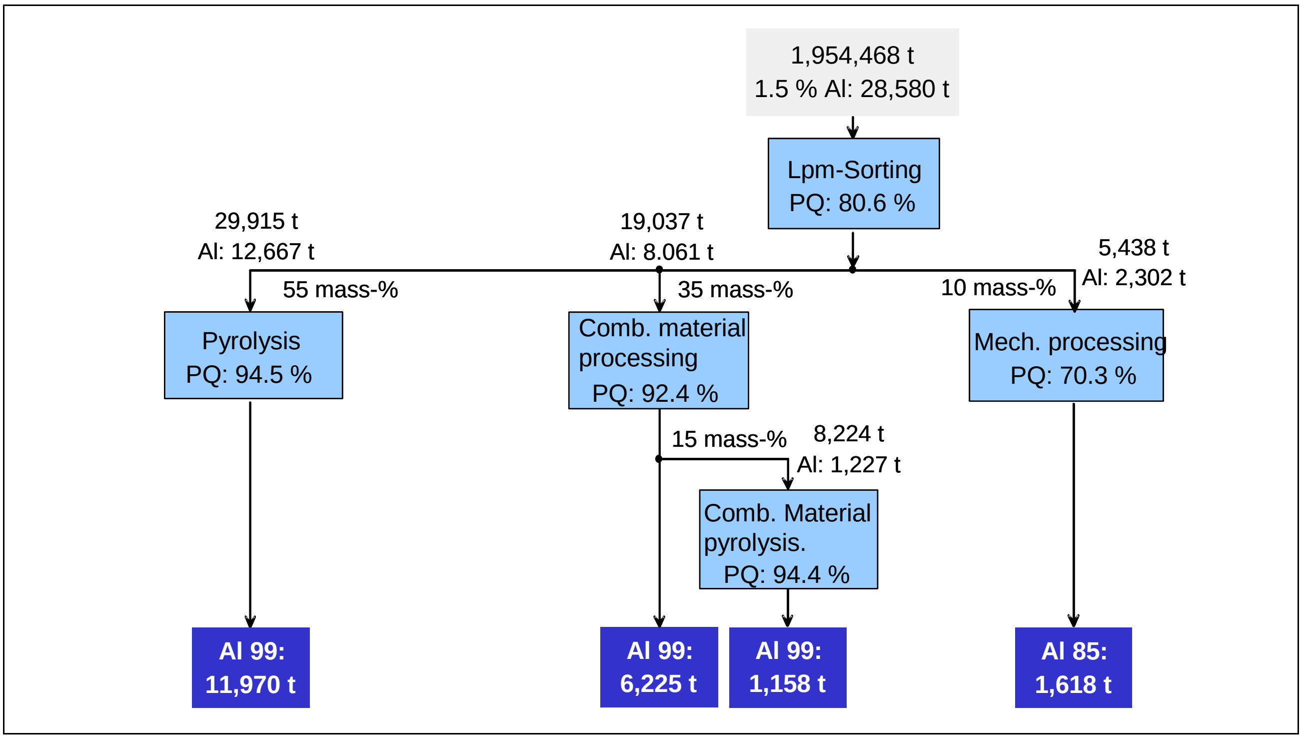

Figure 8: Processing of the Al-fraction of light packaging material [12]

Using a fully automated sorting plant the metal yield of this recycling level would be increased from 80.6 to 94.0 %. Then the process specific energy consumption increases, but related to the larger product quantity this turns to an advantage. Scenario calculations show that in the case of appropriate smelting technique for a future recycling concept NT (exclusively use of newest technology) and its possible implementation in the year 2010 saving potentials of 2,000 respective 1,370 MJ/t of produced alloy result, with an increase of the recovered aluminium amount of 20 and 4 % respectively (figure 9) [12, 13].

These values show an impressive potential, but packaging recycling takes not just done to recover aluminium. The decrease of disposal volume, and the fulfilment of treatment quotas are of main interest for this subventioned system. For the main applications of aluminium, where the scrap contains over 95 % of metal, the material processing and remelting has much smaller improvement potentials, but the processed amounts are much higher, so that every percent point of increased metal yield is a big success.

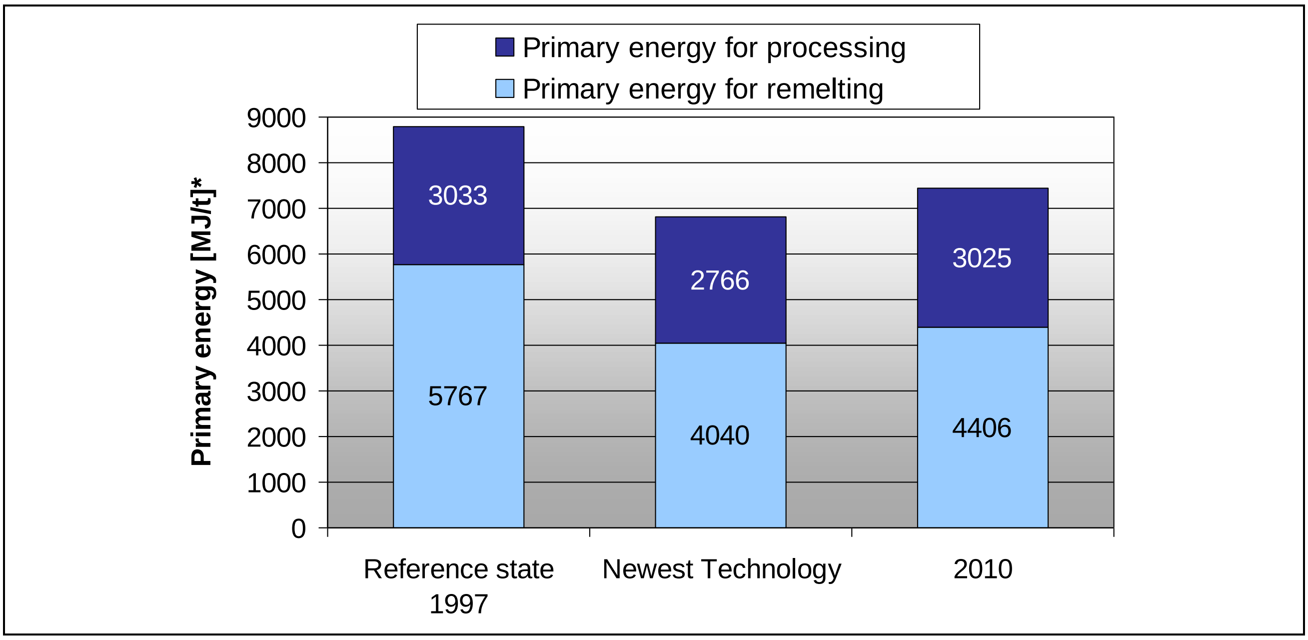

Figure 9: Comparison of the primary energy demand of today's and in the future possible concepts of light packaging recycling (*without Al-recovery from salt slag and dross)[12, 13]

4. Future scrap availability

The growth of aluminium recycling is, unlike primary production, not determined by the industry itself but by the availability of secondary raw materials. Mainly due to improved collection systems for scrap and a strong growth of the amount of present post-consumer scrap recycled aluminium production will increase at a faster rate than that of primary aluminium. This will lead to an increasing share of recycled aluminium of the total aluminium supply in the following years.

The global aluminium demand is estimated to grow about 3 % in average for the next ten years. Of this primary aluminium is expected to grow by 2.7 %, while recycled aluminium should grow by more than 4 % per year in the same period [14].

In Germany the future scrap availability can be estimated on the basis of the produced amounts in the different application sectors and their corresponding life times. Here in contrast to figure 4 not the recycling quota but the future collection quota has to be used to forecast the amount of scrap returning in the recycling system.

Table 5 shows a calculation of scrap amounts for 1998, 2010 and 2020. To estimate the future metal demand in different application sectors yearly growth rates were assumed (line 2). For the evaluation of the different scrap amounts first the reference year of production was determined using the average lifetimes in the application sectors. Then the corresponding metal demand of the sector at the reference year and at 1998 has been taken from the metal statistics [1].

Table 5: Calculation of future scrap amounts in different application sectors in Germany in t

Application	Transport	Gen. Eng.	Elec. Eng.	Construction	Packaging	Home&office	Others	Total
Average Lifetime	12	15	20	25	<1	10	10	
Yearly growth rate	5	3	0	2	1	0	3	
1998								
Reference year	1986	1983	1978	1973	1998	1988	1988	
Amount (ref. year)	387900	65800	61500	150000	104500	63000	121700	954400
Amount 1998	571100	123400	62000	276700	104500	51900	129000	1318600
Collection quota	40	85	80	90	89	50	30	
Scrap amount	**310114**	**80450**	**53080**	**186146**	**95513**	**38622**	**70926**	**834851**
Processing yield	85	95	85	95	75	90	80	
Processed scrap	291809	77834	48181	179993	80768	36338	65564	780487
2010								
Reference year	1998	1995	1990	1985	2009	2000	2000	
Amount (ref. year)	571100	107200	58800	160000	105000	50000	130000	
Amount 2010	1025600	175900	60000	350900	117700	50000	183900	1964000
Collection quota	40	85	80	90	89	50	30	
Scrap amount	**526792**	**121514**	**51024**	**219742**	**100796**	**34000**	**93282**	**1147150**
Improved collection	60	85	85	95	95	60	50	
Scrap amount	607631	123625	53508	228753	105988	37600	111089	1268194
Processing yield	85	95	85	95	75	90	80	
Processed scrap	498438	117444	46334	212755	85884	32120	87204	1080179
2020								
Reference year	2008	2005	2000	1995	2020	2010	2010	
Amount (ref. year)	925182	151782	62000	254000	117040	51900	183180	1745084
Amount 2020	1670600	234460	62000	426118	129580	51900	245100	2819758
Collection quota	40	85	80	90	89	50	30	
Scrap amount	**856872**	**166504**	**53320**	**299085**	**111740**	**35292**	**126110**	**1648922**
Improved collection	60	85	85	95	95	60	50	
Scrap amount	987941	169317	55924	311818	117508	39029	151033	1832570
Processing yield	85	95	85	95	75	90	80	
Processed scrap	810869	160851	48385	288988	95130	33341	117653	1555217

The scrap amount consist of two fractions, the new scrap from the current production and the post consumer scrap obtained from the production at the reference year. Hereby it was assumed that the average amount of fabrication scrap of the end-product manufacturing is about 40 % of the input material and the collection quota of this fabrication scrap is 95 %. The old scrap amount is estimated 60 % of the reference year metal input and the corresponding collection quotas.

The calculation results are presented in figure 10, differentiated by the application sectors. The calculated value of 1998 is in a good agreement with the German scrap statistic (see fig. 6) [10]. The total scrap amount increases from 835,000 t to 1,147,000 t in 2010 and 1,650,000 t in 2020 with an increasing share of scrap form the transport sector, which shows the highest growth rate of 5 %. Further increase of scrap flows results from construction and general engineering.

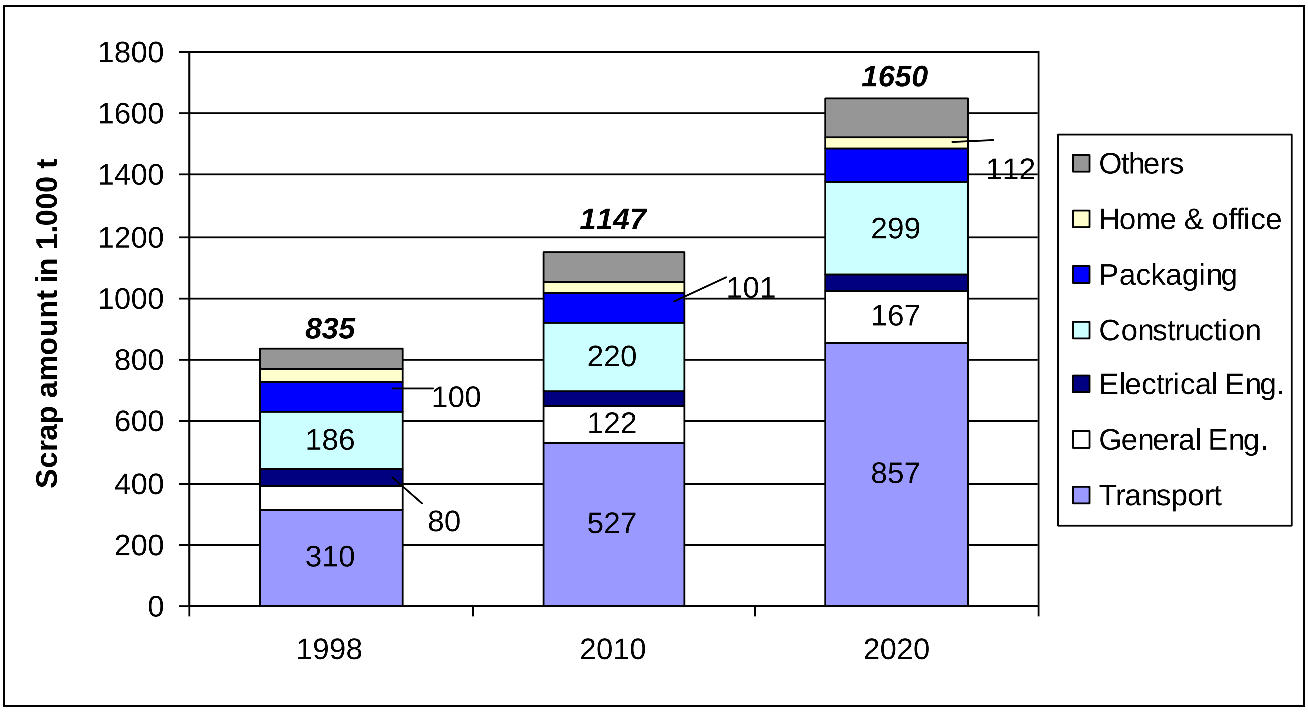

Figure 10: Development of scrap availability differentiated by application sectors

The calculations in table 6 additionally show a further case study of improved collection quotas and the resulting scrap amounts. Main influence on the results again has the transportation sector, where the collection quota is assumed to increase from 40 to 60 % (fig.11). The collection of new scraps will be improved to 98 %. In this case the scrap amount rises about 8 % to 1,270,000 t in 2010 and 1,833,000 t in 2020.

Figure 11 also presents the scrap available for remelting considering the metal yield of material processing. In 1998 780,000 t of processed scrap have been supplied for remelting. The amount will increase to 1,080,000 t in 2010 and 1,550,000 t in 2020 respectively.

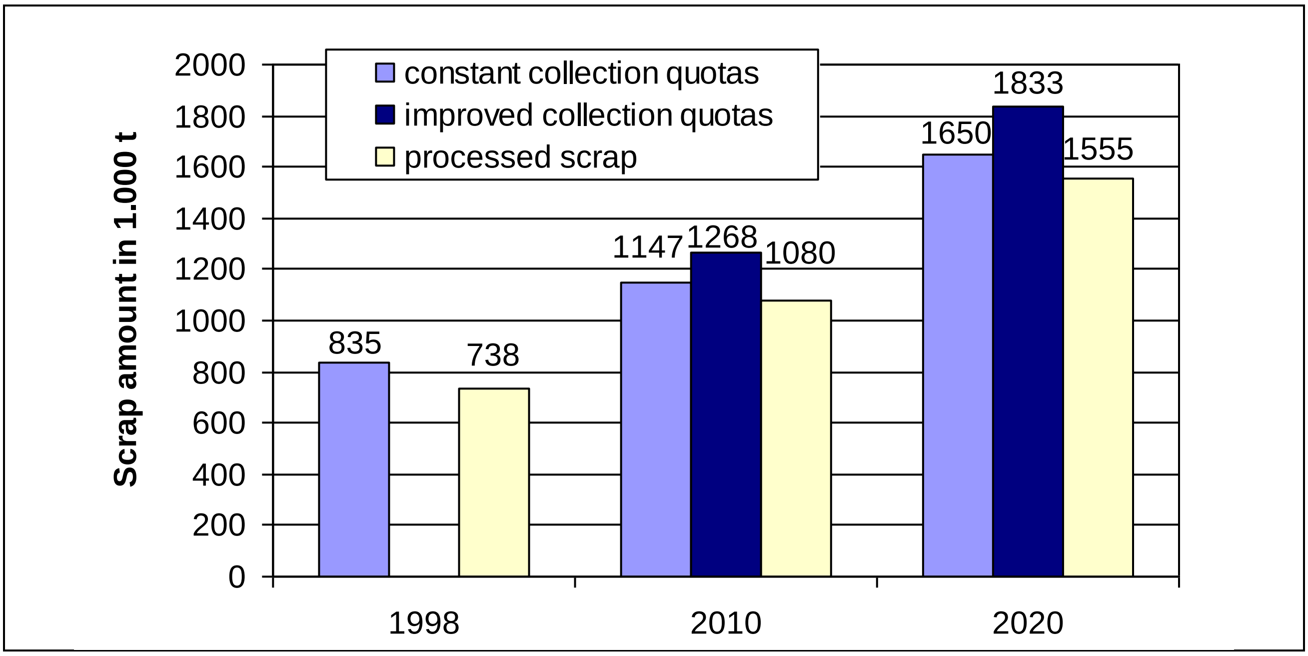

Figure 11: Development of scrap availability with constant and improved collection quotas

5. Summary

This article points out different potentials and limits of aluminium recycling. The scrap availability is located in the focal point of view, which has a major influence on the recycling activities. From this the respective recycled content of the produced metal quantity can be determined, which varies regionally, temporally, product and metal-specifically. On the other hand the recycling quota is a predominantly technique-specific measure for the success of recycling activities, which also has to consider the collection of secondary raw materials. The recycling technique can be described unique over metal yield and energy consumption. Furthermore for the recycled content and the recycling quota the quality of the raw materials, i.e. the condition, the alloy status and the metal content are of high importance. Finally this article estimates the future amounts of scrap arising in the different application sectors. It could be shown that the overall scrap availability increases by 37 % until 2010 and 97 % until 2020. Further calculations now have to identify the share of different alloy groups of these total amounts to support operative recommendations for the secondary aluminium smelters.

6. Acknowledgement

The presented work was carried out in the context of the Collaborative Research Centre 525 "Resource-orientated analysis of metallic raw material flows", established in 1997. Thanks are due to the German Research Council (DFG) for financial support.

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