Aluminium Recycling in Germany
- Status and Potential -

G. Rombach, B. Friedrich

IME process metallurgy and metal recycling, department and chair of the RWTH, Aachen University of Technology, Intzestr. 3, 52056 Aachen/Germany

Introduction

Recycling of metals is an important source of raw materials for the increasing applications since beginning of its use. It has always been worthwhile to use the economic value of metal bearing wastes from processing and used products to recycle metals. Ecological aspects apart from the economic interest are today:

- saving of resources
- reduction of emissions and wastes
- reduction of dumps and
- saving of energy

Increasingly recycling is included also into the discussion about a sustainable development in metal-industry. With the recycling of aluminium even renewable raw materials are discussed as well as a generation contract regarding the energy used for primary aluminium production. In the long run any use of products leads to a material distribution of the used metals, this should be regarded as a challenge for the development of collection, processing and remelting technologies.

Despite the undisputed economic and ecological advantages of metal production from secondary raw materials there is a set of factors, which limit expenditure and use of recycling. These are, among other things, minimum metal contents of the secondary materials, the production of secondary wastes, the multiplicity of the different types of alloy and pollutants, a rising number of composite materials and the effects of user-specific material treatment on the achievable metal quality. However the different quality and availability of the raw materials for the production of the different product alloys show that for an evaluation of recycling systems the technical operating parameters are not sufficient alone as criterion for the selection of certain procedure versions or - alternatives.

Keywords

Sustainable development of the metallurgy - recycling of metals as important source of raw material - economic and ecological advantages of the metal production from secondary raw materials - Time and aspects of quality limit the availability of secondary material -technological development becomes only assessable in the total concept of collection, processing and remelting.

The availability of secondary raw materials

The supply of metal production with secondary raw materials is subject to various influences, which are described in the following. These are in particular time aspects and aspects of quality, which limit the availability of secondary material. With an exact analysis of the existing metal flows and the assigned technologies develops a further problem of the recycling, the definition of the recycling quota and the recycled content which describe and evaluate recycling activities. This abstract presents technical-metallurgically based solutions for these problems.

The difference between the aluminium quantity used and the quantity produced in Germany is substantial however according to the metal statistics. The question arises how the high metal requirement of the processing industry is covered and which role thereby plays the recycling. According to figure 1 the recycled content of the production would amount only to about 18 %, whereby only the secondary aluminium production on cast alloy base is compared with the entire in the semi-finished material and casting area assigned metal quantity [1]. This leads undisputed to false conclusions.

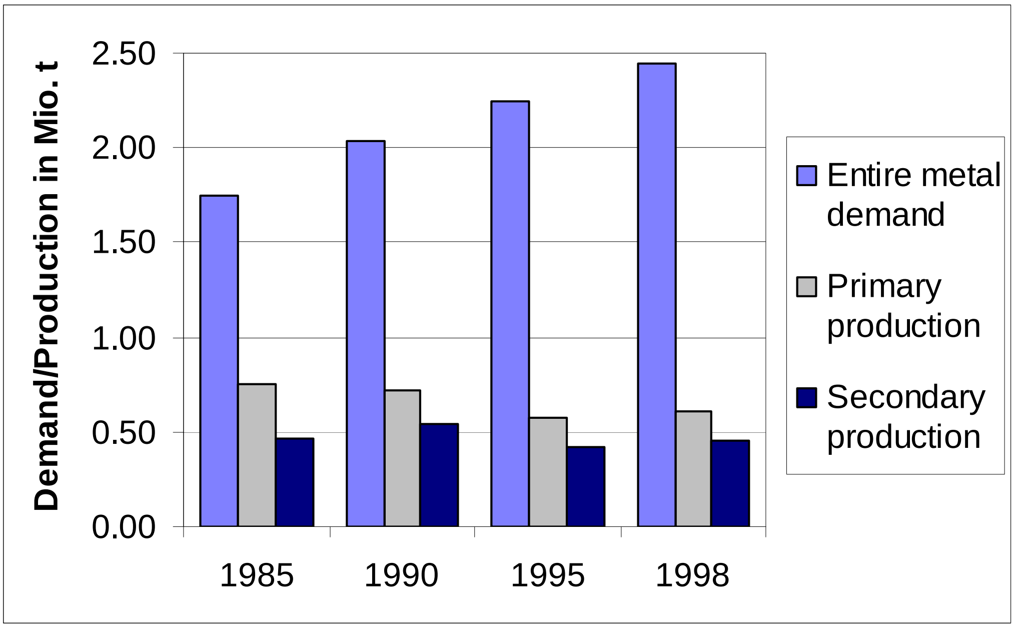

Figure 1: Development of entire metal demand, primary and secondary production of aluminium in Germany [1]

For the correct definition of the term “recycling” at first a qualitative and quantitative description of the scrap flows from the areas of application is important, as well as their connection to existing recycling routes. Therefore a division of Aluminium materials in two groups of alloys is important. In cast alloys the content of alloying elements, above all silicon and copper, is rather high, wrought alloys in comparison are lower alloyed, usually with magnesium and manganese and should therefore be separated and if possible should arrive pure sorted in the recycling cycle. Figure 2 shows some basic differences.

Casting alloys:

- **relatively high alloying contents (Si, Cu, Mg, Zn)**
- **AlSi7Mg, AlSi12, AlSi6Cu, AlZn5Mg**
- **casted engine parts, wheel rims, doorhandels, pans**

Wrought alloys:

- **relatively low alloying contents (Mn, Mg, Cu, Ni, Zn, Si, Fe)**
- **AlMn1Mg1, AlSi1Mg, AlCuMg, AlZnMgCu,**
- **tins, foils, extruded shape, conducting material**

Figure 2: Comparison of casting and wrought alloys

The material separation is limited by application and collection inclusive trade. Figure 3 shows the German application divided by aluminium casting and wrought alloys, that is dominated by the traffic sector [2]. In each of these ranges of application, with exception of the packing area, casting and wrought alloys often are mixed after use.

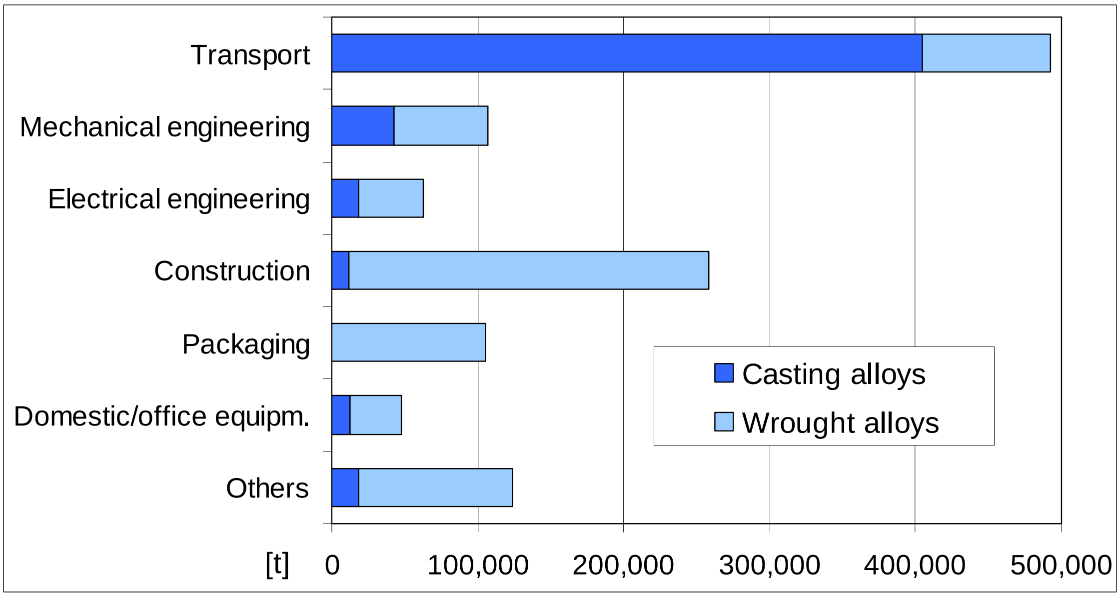

Figure 3: Use of aluminium casting and - wrought alloys 1997 [2]

Apart from this rough division in casting and forgeable alloys exists a further distinction in group of alloys, which results from type and quantity of the mainly used alloying elements. Figure 4 shows an division of aluminium alloys commonly used in statistics. These can be mixed only within close limits among each others and are collected individually if possible.

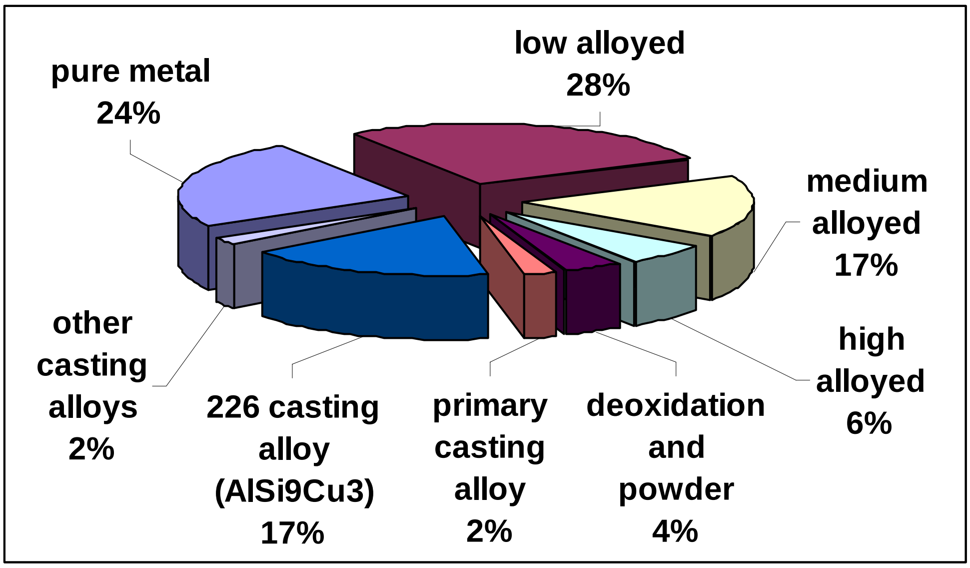

Figure 4: Alloy shares of aluminium application in Germany

With the view of individual ranges of application further distinctions must be made: On the one hand closed recycling cycles exist, so called closed loop recycling, if scrap is supplied to a same-alloy reapplication, e.g. with beverage cans and window frames. Open recycling cycles, so called open loop recycling, exists if secondary raw materials are after smelting supplied to another use also in form of other alloys. Here in particular the refiner (secondary smelters) should be mentioned, which produce cast alloys for the automobile industry exemplary out of a mixture of different old and new scrap (figure 5).

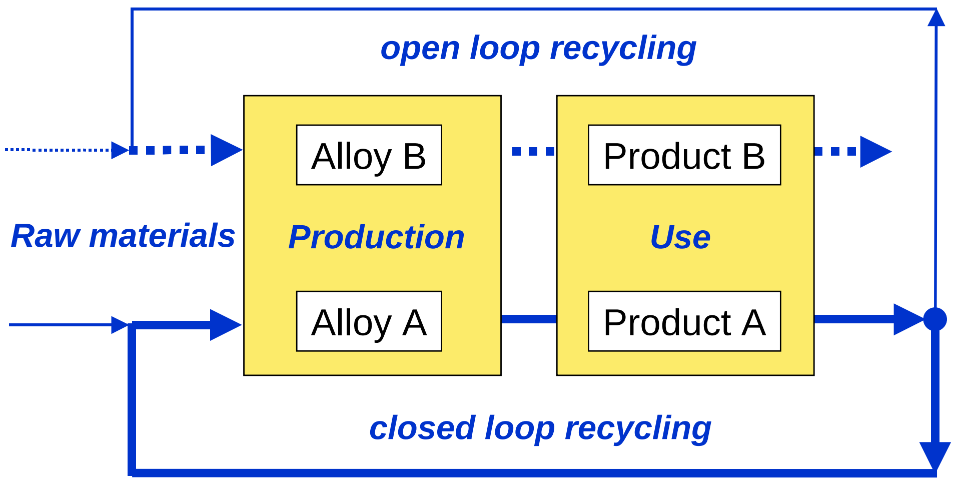

Figure 5: Open and closed recycling cycles

Besides this idealised cases a transient area in material and spatial regard exists. Materially, since also forgeable alloys are converted into cast alloys and so achieve a material-technical modification. Spatially since production scrap is recycled externally not only in-house, and thus not remain in a closed cycle. Sort-pure wrought alloy scrap is recycled directly by the remelters to rolling and extrusion ingots, which go then into closed and open recycling cycles. Mixed and contaminated scrap is exclusive recycled by the refiners into cast alloys and go usually into open recycling cycles [3].

While the product is in use the metal is bound in so material stock. The overall stock quantity of aluminium is estimated to 600 - 700 millions t world-wide. The distribution of the metals and the return flow into the production cycle are thereby spatially, materially and temporally different. The stock characteristics of aluminium can be described on the basis of selected product groups, products, product sections or types of use (table 1). Aluminium packaging for example was a high spatial distribution with small product size. The material purity can be high (menu bowl, beverage can), middle (cover caps, painted foils) or low (multi layer foils, vaporised bags). The retention time is small with an average life span of half a year [4].

Stock characteristics		**Packa-ging**	**Transport**		**Con-struction**	**General engineering**	**Electrical engineering**
			train/plane	car			
spatially	size	small	high	middle	high	middle	middle
	propagation	high	small	high	middle	middle	high
materially	purity	varied	high	small	high	middle	varied
temporally	retention time	small	high	middle	high	high	varied

Table 1: Stock characteristics of aluminium products in selected use areas [4]

The temporal aspect is shown in the next figure of production periods, life span, recycling quotas, return flow quantities of resulting aluminium scrap and the resulting difference to the present requirement in different applications, figure 6.

Today for example scrap from mechanical engineering arises, which was produced between 1980 and 1990, thus has a life span of 10 to 20 years. Only packing materials arrive back into the secondary cycle within half a year. By the temporal shift of the scrap flow in relation to the production the difference between resulting scrap quantity and necessary metal becomes larger. This is still enlarged by the high growth rates in the aluminium application.

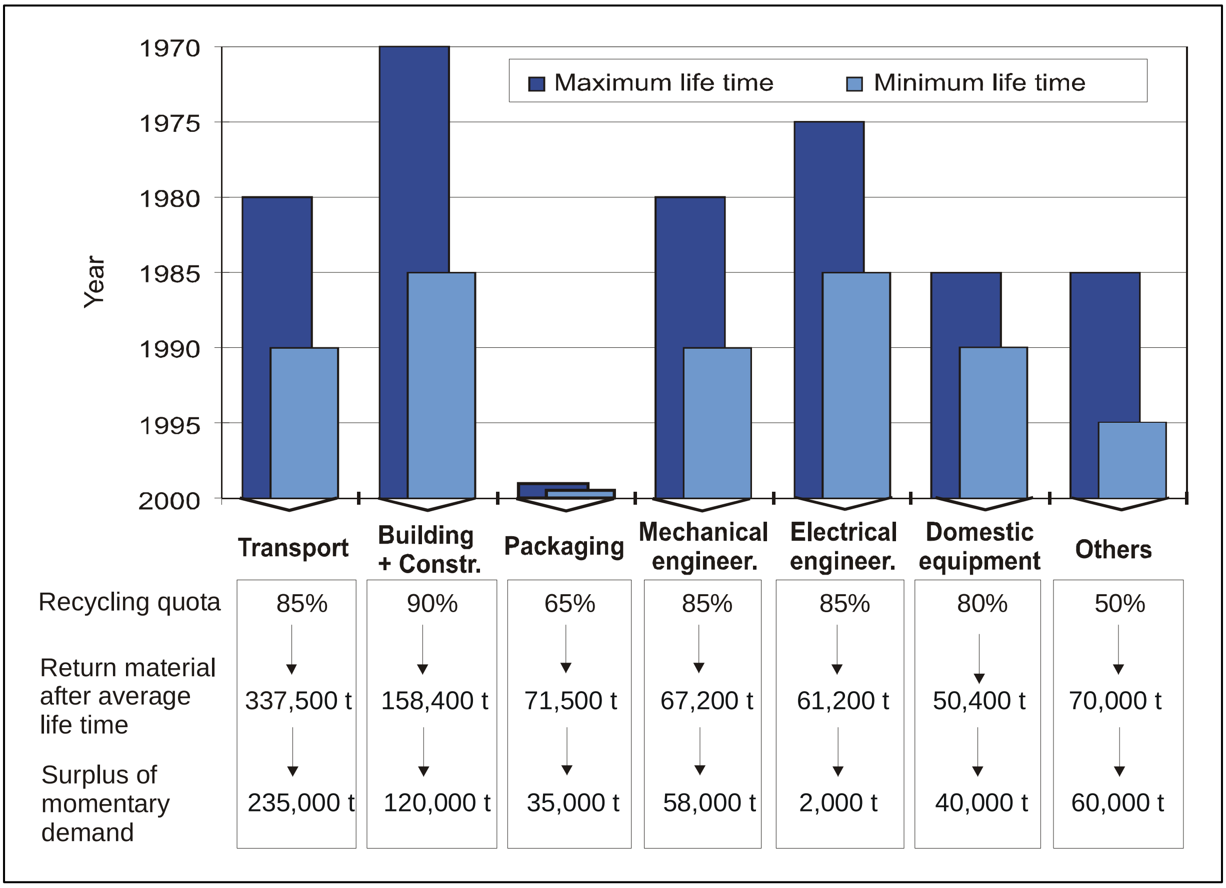

Figure 6: Recycling quotas and return quantities resulting from different lifetimes for different applications under the assumption of complete collection

The determination of the scrap amount is based on the depot quantities of individual applications and their recycling quotas. The recycled content resulting from this estimation would amount for a complete collection of the scrap to 60%. Reason for the difference to the value of 18%, specified before, is alone the determination of the recycling quota. Following some definitions [5, 6]:

For metal recycling the recycling quota consists of the collection quota and the technical recycling quota. This separation clarifies also the different levels of the recycling in figure 7, their knowledge represents the basis for a resource-oriented view.

To distinguish

- the collection quota CQ: It determines the quantity of available secondary material that is registrated in collecting system, related to the quantity used in the product.
- the technical recycling quota RQ_t: Here the quantity of material is determined, which after the collection and recycling actually is available for utilisation at the end of the process as secondary metal, i.e. it is the yield of the technical process.

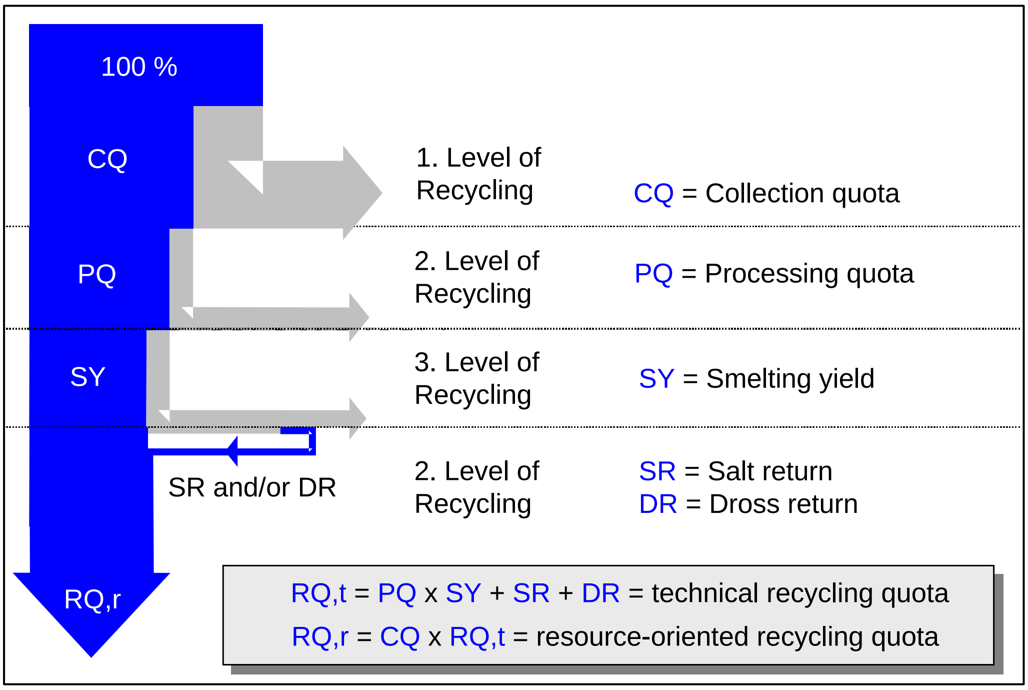

Figure 7: Definition of the recycling quotas for collection, processing and smelting [5]

The technical recycling quota consists again of two sections, PQ, which indicates the processing quota, that is how much metallic aluminium from the collection is supplied for melting; and the smelting yield SY, which indicates, how much aluminium is won as liquid metal, i.e. herein is taken in account the return flows from salt slag and dross treatment (SR, DR).

By the example of the German packaging recycling the different levels of the recycling can be explained.

In the year 1997 consumption of light packaging material (LPM) that are plastics, tinplate, composites and aluminium, amounted to 1,778,198 t [6]. Of the used packaging material 1,582,596 t collected, which corresponds to an collection quota of 89 %. At the same time 389,525 t of other materials arrived by false collection into the LPM mixture. In the sorting plant plastics, tinplate and composites are separated and an aluminium-bearing fraction (LPM Al40) is supplied to the further utilisation in mechanical processing, composite processing and pyrolysis. This amounted in 1997 to about 55,000 t.

The appropriate recycling quota is calculated in figure 8. The technical recycling quota amounts to 68,4 % and the resource-oriented recycling quota is 61,7 %.

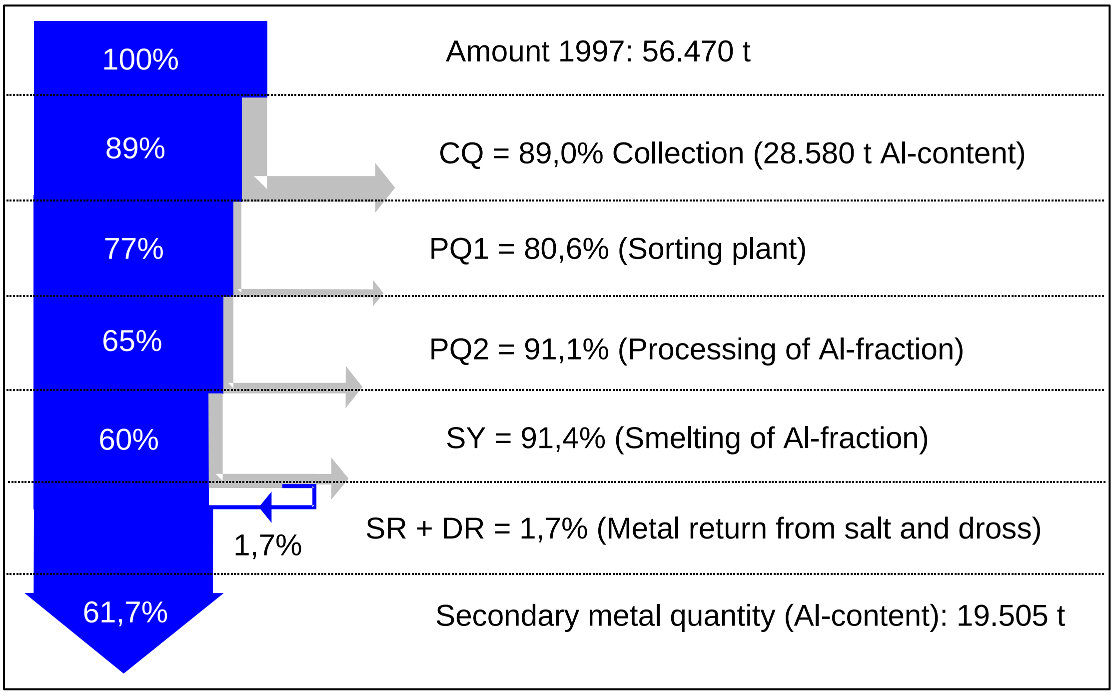

Figure 8: Determination of the recycling quotas for Aluminium light packaging material [6]

For the different areas of use for aluminium the determined quotas vary [4]. The span of collection reaches from approx. 25% for the aluminium content of urban waste up to almost 100% of the quantity from the constructing sector, in such a way it becomes a crucial element for the success of a recycling concept in regard for a most efficient utilization of secondary raw materials (figure 9).

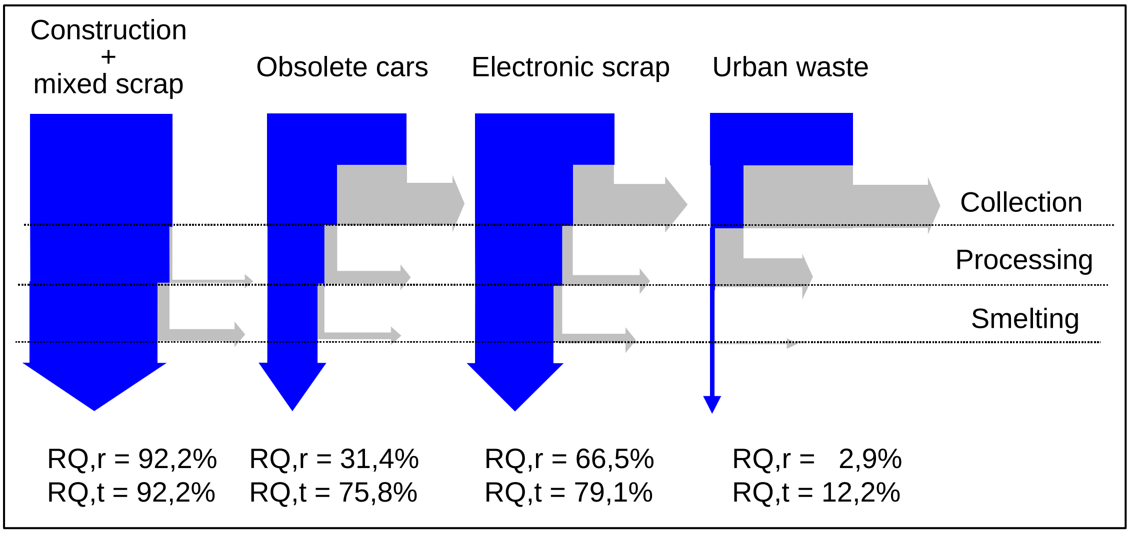

Figure 9: Technical and resource-oriented recycling quotas for aluminium products [6]

The resource-oriented recycling quota defines thus the recoverable metal content of the assigned materials or components.

In contrast to it the recycled content is the share of secondary metal, which is used for processing. If the collection quota of secondary raw materials is considered for the determination of the theoretical recycled content, it is reduced from 60 to 46% (viz. figure 6). The recycled content lies usually below the recycling quota, since with rising metal consumption more primary metal must be produced, than is corresponded to the losses during usage.

The recycled content however is unsuitable as standard of valuation for recycling success, since it represents a regional valve, which is often strongly falsified by the existing open scrap market and the rising metal demand of application.

Quality influence of secondary raw materials on the aluminium recycling

Apart from the availability also the quality of the feed materials is of crucial importance for the recycling, i.e. their condition and above all their alloy composition.

Refining of the very ignoble metal aluminium is only possible within very small limits (table 2) and accompanying metals such as iron, manganese, silicon, magnesium, copper and zinc remain predominantly soluted in the metal phase. For this reason during primary aluminium production refining is done before reduction, for recycling this means an exact separation of the scrap concerning type of alloy and purity must be done already before melting. If this is not succeeded only a diluting with primary metal or blending of different melts as a possibility for alloy adjustment remains.

Kind of refining	**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
Intermetallic precipitation	Removal of Fe, Mn, Si
Vacuum distillation	Removal of Li, Zn, Mg, Na
Addition of primary aluminium	Dilution of accompanying elements
Addition of alloys	Blending, dilution of single accompanying elements

Table 2: Possible melt treatment of remelted aluminium

As consequence from the alloy situation in practice two types of furnaces became generally accepted. Sort-pure scrap and new scrap are usually melted in large volume open-hearth furnaces, mixed new and old scraps, dross and turnings are melted in smaller, more flexible salt bath rotary furnaces. This distinction is also found in the different procedure routes of the second and third recycling level (figure 10).

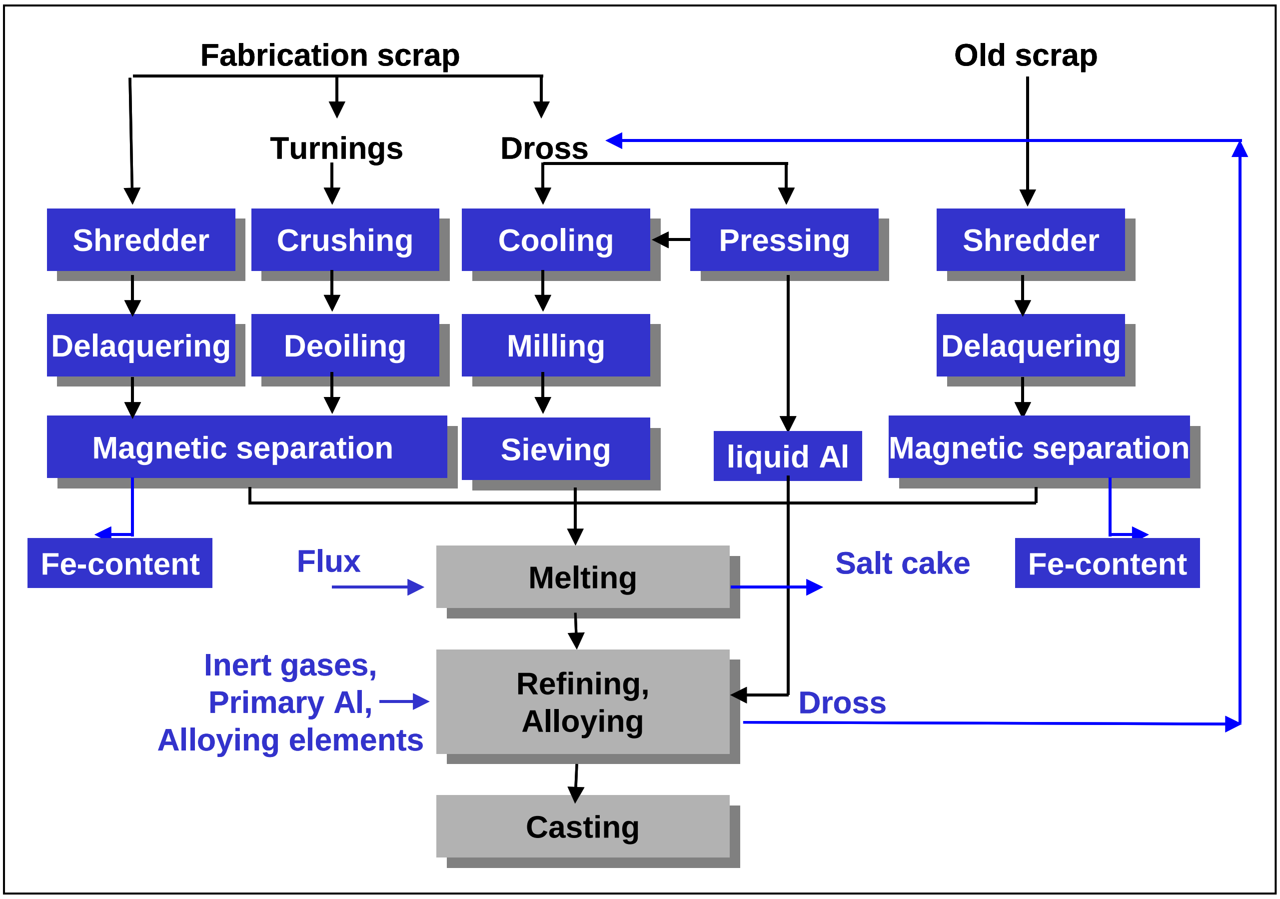

Figure 10: Flow sheet of the aluminium recycling (level 2. and 3.)

Despite of rising return quantities from production and use the intensified sort-pure recycling of forgeable alloy scrap from refiners leads to a lack of diluting material for the secondary smelters. Through their necessarily increased application of primary metal their cost situation is getting more difficult.

Accordingly, the scrap application of German aluminium refiners (figure 11) shows decreasing shares of new scrap in the years 1975-1999, whose share was reduced to 30 %, while the share of old scrap developed in opposite direction [7].

For the example of aluminium the scrap balance of 1997 in figure 12 clarifies the aspects of scrap availability and quality. First a small export surplus is to be detected, which consists of old scraps, fabrication scraps and turnings.

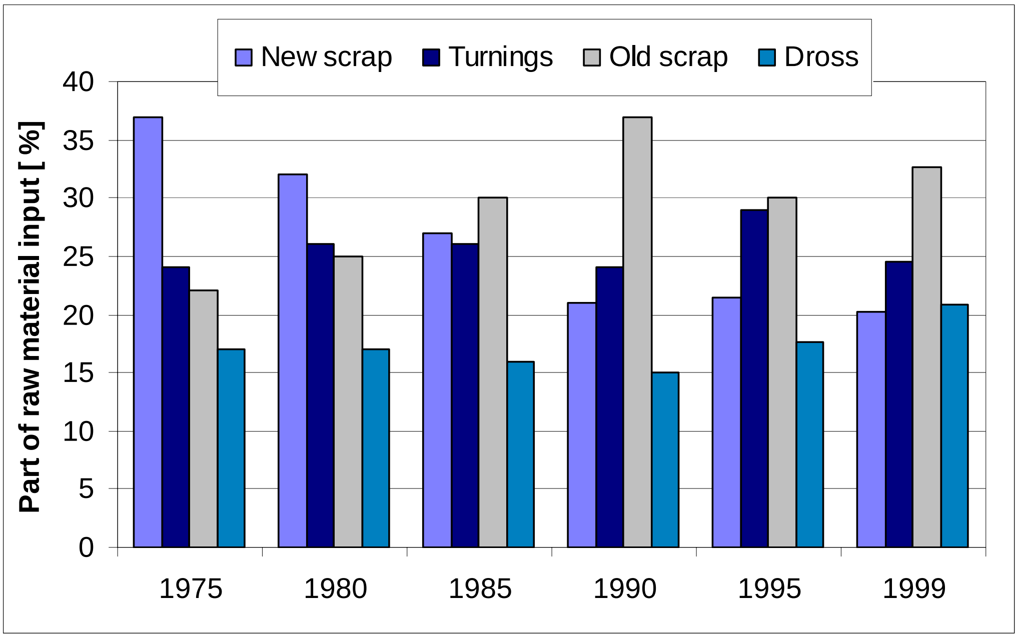

Figure 11: Development of the scrap supply of the German secondary aluminium smelters from 1975 to 1999 [7]

For the secondary aluminium production approx. 400,000 t scrap (Al-content) were used, of that about 70,000 t of wrought alloys became remelted pure sorted. Further wrought alloys were remelted in the cast houses of primary smelters (174,900 t) and the semi-finished material plants (190,000 t) [8, 9]. The amount of approx. 920,000 t of fabrication scrap is re-used directly in the semi-finished material manufacturing as cycle material and is thus statistically not registered.

The shown scrap application plus an imported quantity of 168.000 t secondary aluminium and the scrap share of the foreign primary metal results in a real recycled content of the German total production of 37 %. This is a mass-referred average value of the individual areas of application.

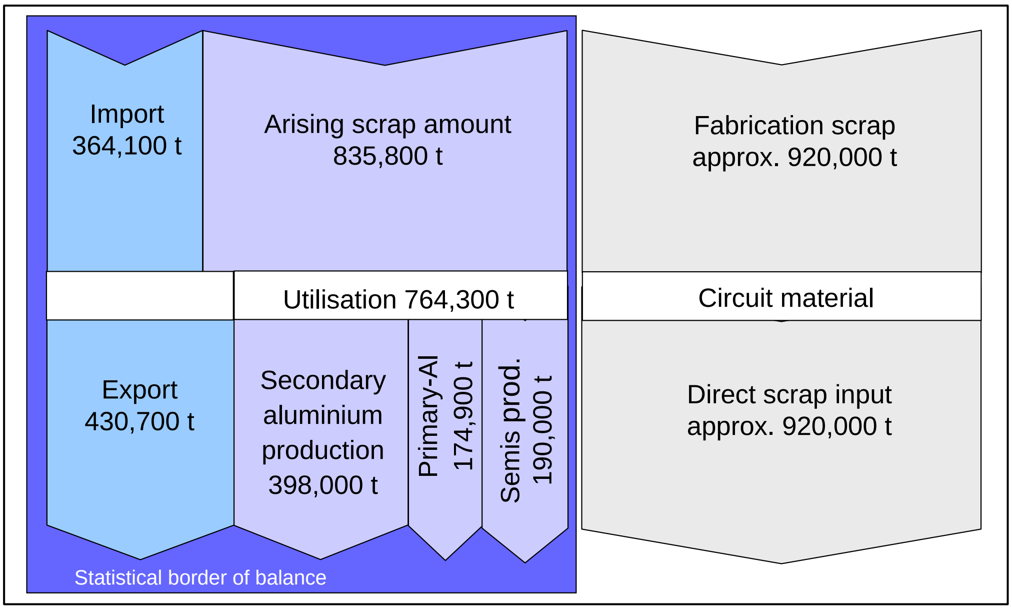

Figure 12: German scrap balance 1997 [8, 9]

The interaction between the product areas can be quantified by the existing scrap flows (figure 12). An alloy cascade results, whereby the recycling activities increase the alloy content of the entire stock. Unalloyed aluminium forms the starting point of this material flow and has therefore the smallest recycled content. Lowering of the alloy status, i.e. a reversal of the usual supply direction in figure 13 is only possible with a high expenditure, comparable to the primary production.

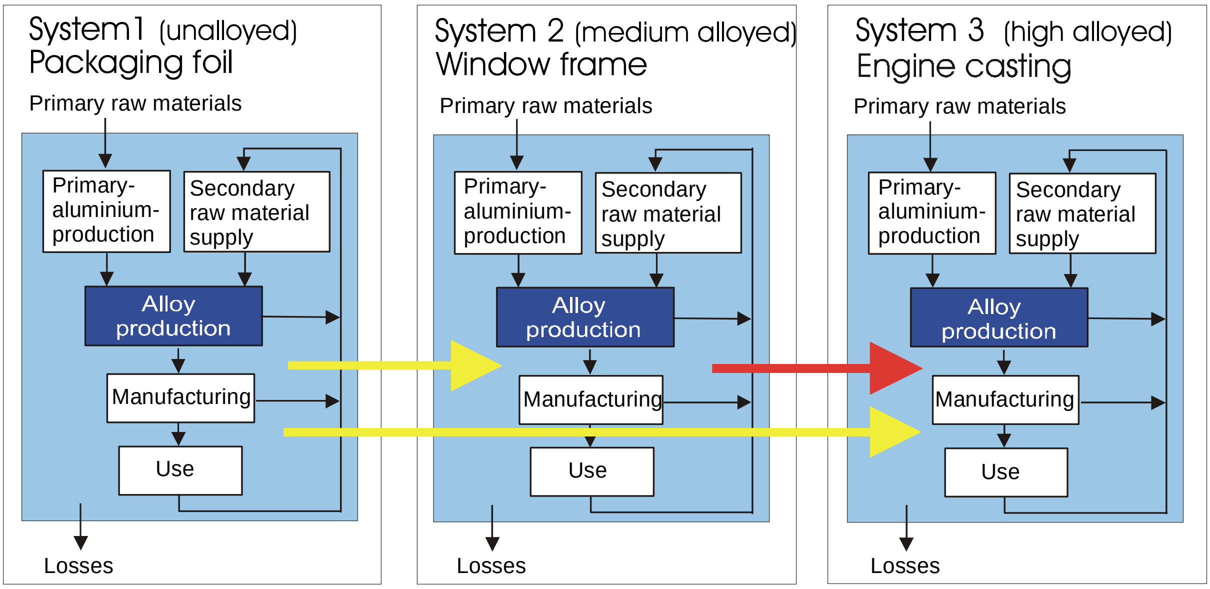

Figure 13: Interaction between the recycling systems

In the long run the success of recycling activities can only be evaluated by the metal quantity recovered and thus by the saving of primary metal in the total system of aluminium, whereby only about 10 % of the energy expenditure of the primary production is needed. Beyond that the sort-pure collection and processing works against an enrichment of alloying elements in the recycling cycle and save thus the maximal applicability of the secondary raw materials that is expensive anyway by its shortage.

Energetic evaluation

For the energetic evaluation of recycling first the question of the optimal technique for the processing of the different materials is to be answered. Thereby the energy expenditure of every material sinks with rising recycling quota, or rising recycled content of a closed product cycle shown in figure 14. An increase of the recycling ratio leads however starting from a certain limit value to very strongly rising expenditures, since then the specific energy consumption rises super proportionally with the high expenditure for collecting and processing.

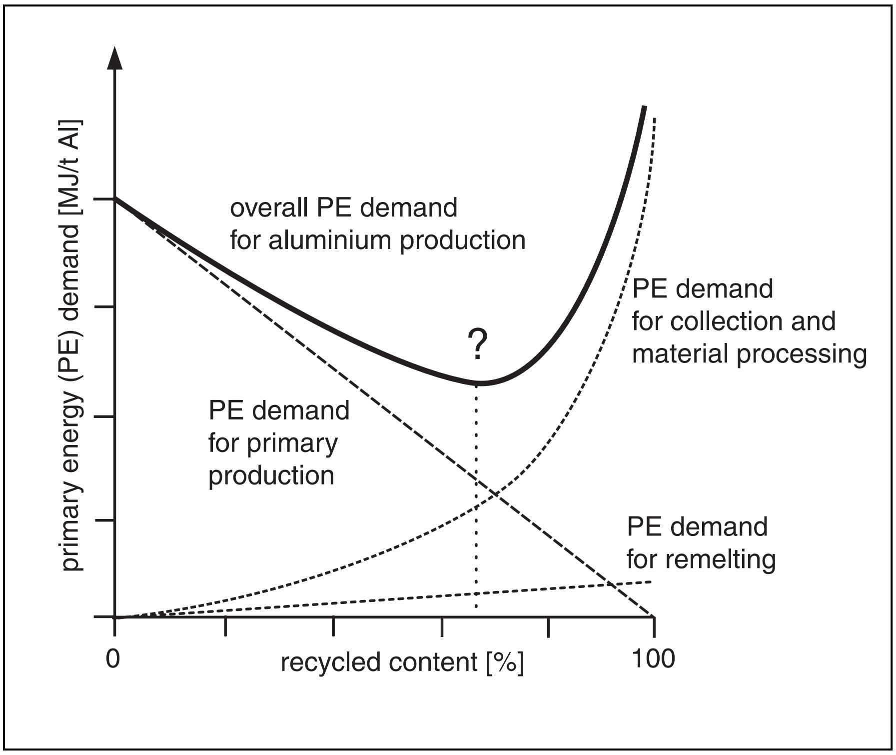

Figure 14: Qualitative determination of an optimal recycling ratio regarding the primary energy expenditure

Beyond that the condition of the scrap and in particular their aluminium content intends the power requirement for the remelting. Figure 15 shows a strong rise of the energy requirement below approx. 80 % aluminium content. Below that value the accompanying substances of the aluminium decide on the application in which respective melting or processing unit they are treated. In melting practice an optimal melting yield is achieved only by special material mixtures.

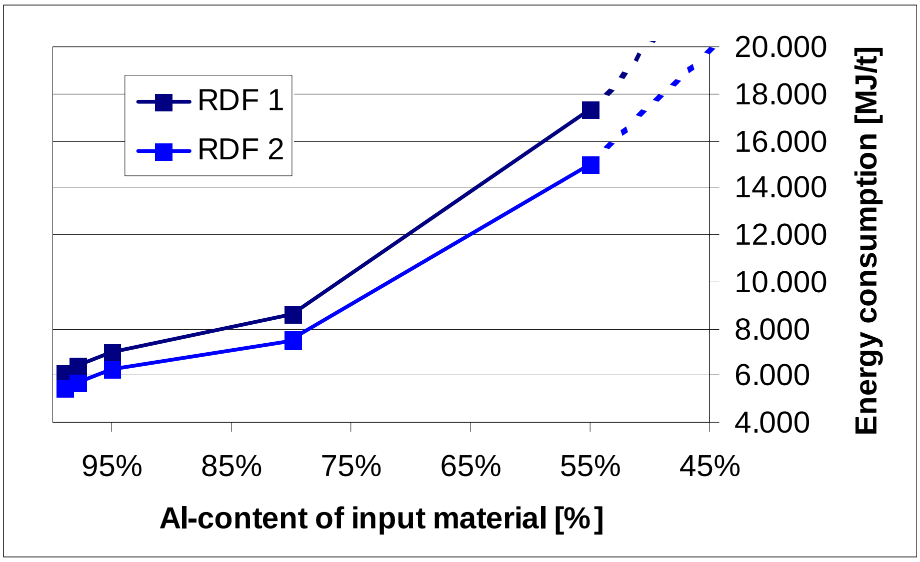

Figure 15: Dependency of the melting on the aluminium content of the materials

An example of aluminium-poor raw materials is the aluminium fraction won from light packaging materials. Here also the potentials of the technological development and in particular the interaction between processing and melting practice can be clarified. Figure 16 shows the existing system of the packaging material recycling. The aluminium fraction from the sorting plant, with 40 % aluminium content and predominantly organic residues can not be processed directly pyrometallurgically. With the combination of mechanical and thermal processing routes a high-quality fraction with approx. 99 % of aluminium content is obtained which can be processed with a melting yield of over 90 %. The average processing quota is situated however with about 73.4 % relatively low.

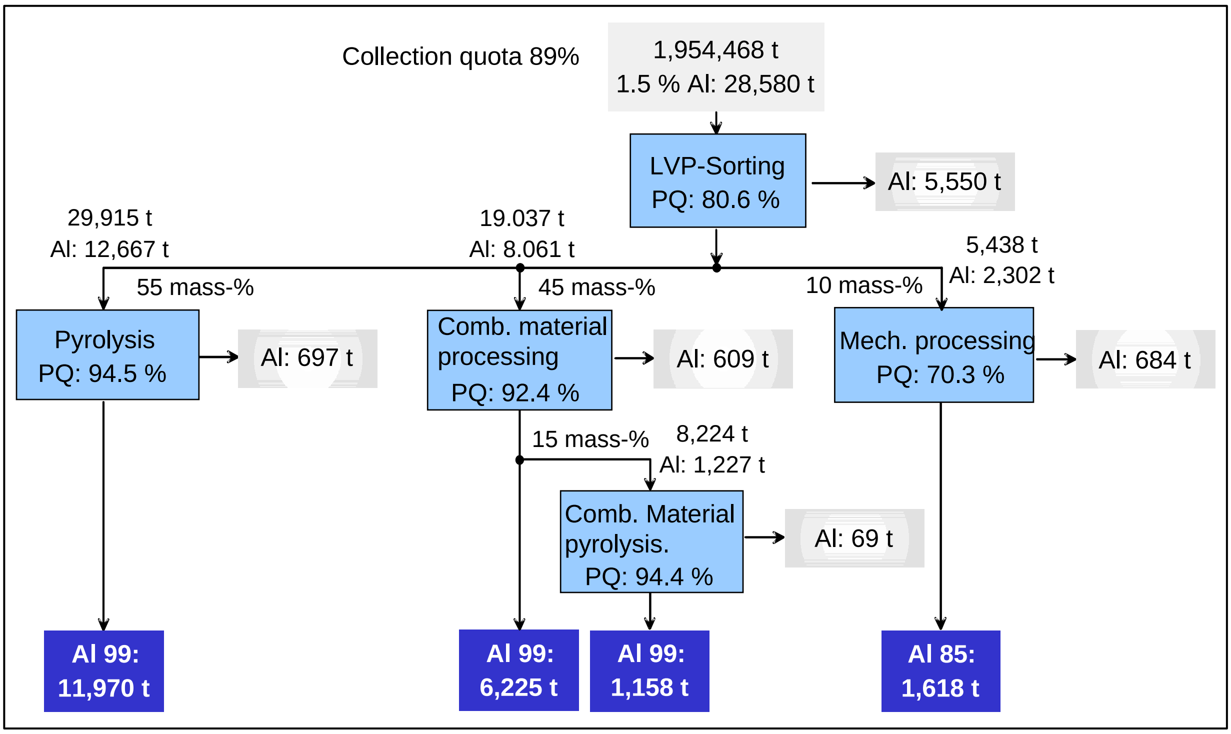

Figure 16: Processing of the Al-fraction of light packaging material [10]

Alone by the application of a fully automatic sorting plant the yield of this level could be increased from 80,6 to 94 %. Then process specifically the energy consumption rises, related to the larger production however this turns into an advantage. Scenario calculations show that in the case of appropriate melting technique for future recycling concepts NT (exclusively newest technology) their possible usage in the year 2010 saving potentials result of 2000 or 1370 MJ/t of produced alloy, with an increase of the aluminium quantity around 20 or 4 % (figure 17) [10, 11].

Beyond that detailed analysis of the recycling processes by means of process chain modelling points out further important, often not obvious aspects of the recycling or individual processes.

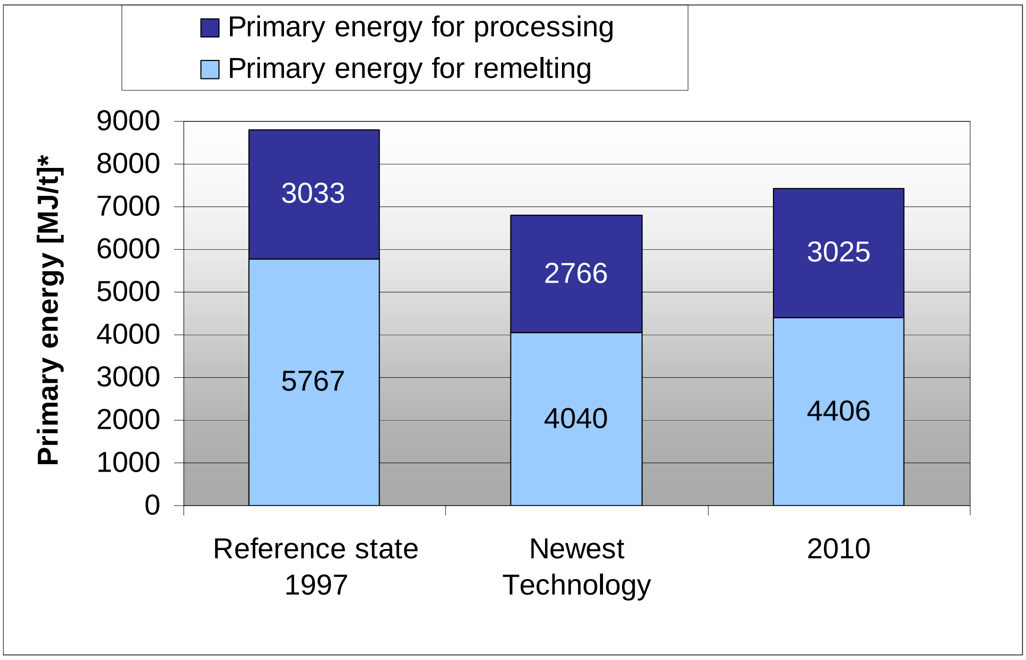

Figure 17: Comparison of the primary energy demand of today's and in the future possible concepts of light packaging recycling [10, 11]

Figure 18 shows besides the allocation of the primary energy the distribution of the final energy exemplarily for the energy carrier Diesel. It shows how important the transportation during the collection and afterwards to the sorting plants is. Likewise the utilization of the aluminium fraction in the centralised pyrolysis operations in Southern Germany is connected to high transport expenditures.

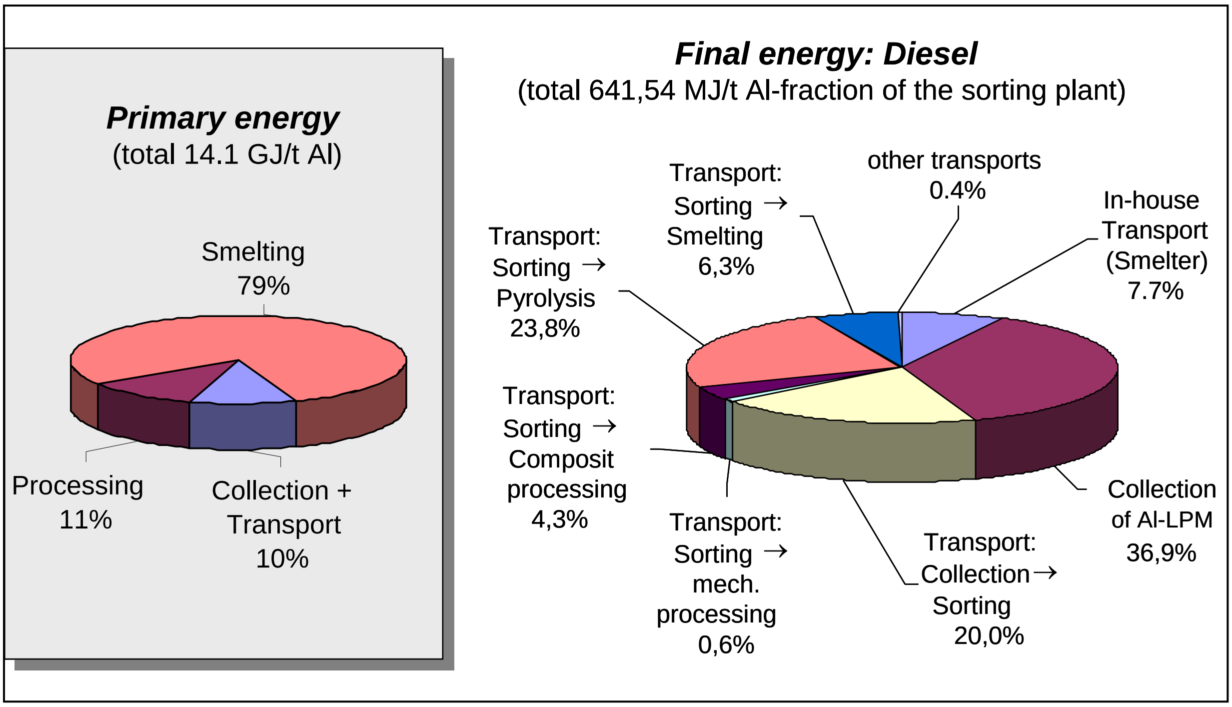

Figure 18: Classification of the primary and final energy consumption for the packaging recycling by the example of Diesel fuel [10]

Summary

This article confronts requirement and feasibility of the aluminium recycling. The scrap availability is the focal point of the view, since it exerts an influence on the recycling activities, equally important for all metals. From this the recycled content of the used metal quantity can be determined, which varies regionally, temporally and product-specifically. The recycling quota is in comparison a predominantly technique-specific measure for the success of recycling activities, with which depending upon the selection of the definition also the collection of secondary materials must be considered. For recycled content and quota is the quality of the raw materials, i.e. the condition, the alloy composition and the metal content of importance. The recycling technique can be described over the metal yield and the energy requirement, whereby as possible an entire recycling concept with processing and melting technique has to be evaluated and not an individual process.

Future developments will have to aim at the increase of the efficiency of collection and utilisation of secondary raw material sources up to an optimum. The energy expenditure for the recycling represents however only one element, which are usually consulted in connection with the resulting emissions for the ecological evaluation. In order to arrange a sustainable development of the metallurgy, also economic and social aspects of the resource management are to be included into the view.

References

[1] Metal statistic 1988-98, 86. Vol., Metallgesellschaft, Frankfurt a.M.; World Bureau of Metal Statistics, Ware, 1999

[2] Aluminium end-use: EAA 900 / 1997, Gesamtverband der Deutschen Aluminiumindustrie GDA, Düsseldorf, 1998

[3] Rombach, G.: Aluminium in open and closed loops. Aluminium 74 (1998) 6, S. 421

[4] Bauer, C.; Rombach, G.; Teschers, R.; Wolf, S.; Zapp, P.: Einbindung von Nutzungsaspekten in die Stoffstromanalyse metallischer Rohstoffe. Metall 54 (2000) 5, S. 205-209

[5] Wolf, S.; Meier-Kortwig, J.; Hoberg, H.: Modelling the material flow of recycling processes for aluminium alloys by means of technical recycling quotas. Global Symposium on Recycling, Waste Treatment and Clean Technology, REWAS 99, ed. by Gaballah, E.; Hager, J.; Solozabl, R., San Sebastian, Spain 1999, pp. 1023

[6] Wolf, S.: Untersuchungen zur Bereitstellung von Rohstoffen für die Erzeugung von Sekundäraluminium in Deutschland - Ein Informationssystem als Hilfsmittel für das Stoffstrommanagement. Dissertation, RWTH Aachen, 2000

[7] VDS-Scrap input statistic. Vereinigung Deutscher Schmelzhütten (German Refiner Association), Düsseldorf, März 2000

[8] Aluminium scrap balance 1997. Bundesamt für Wirtschaft, II 6 NE-Metallstatistik, Eschborn, 1998

[9] Survey results of NE-Metallfachstatistik. Market Supply with Aluminium, Bundesamt für Wirtschaft, Eschborn, 1999

[10] Sonderforschungsbereich SFB 525: Resource -orientierte Analysis of Metallic Raw Material Flows. RWTH-Aachen, 2000, http://sfb525.rwth-aachen.de

[11] Rombach, G., Zapp, P.; Kuckshinrichs, W.; Friedrich, B.: Technical Progress in the Aluminium Industry – A Scenario Approach. in: Light Metals 2001, ed. by Anjier, J. L., TMS, Warrendale, USA, pp 1131-1137

Authors

Dr. Ing. Georg Rombach finished the study of non-ferrous metallurgy at the RWTH Aachen in 1992 and earned his PhD in metallurgy and material science in 1997 at IME. At present he works on his lecturing qualification within the area of material flow management and recycling.

Prof. Dr. Bernd Friedrich is head of the IME department of process metallurgy and metal recycling at the Aachen University of Technology (RWTH). He received his PhD at IME in 1988, worked for GfE/Metallurg. Inc. as R&D manager and head of profit centre smart materials from 1988 to 1995 and became plant manager for Varta batteries AG from 1995-1999. Since July 1999 he is directing the IME (www.metallurgie.rwth-aachen.de). Light metals recycling is one of the core areas in Aachen besides vacuum metallurgy and surface coating.