Chapter 10

LIMITS OF METAL RECYCLING

Georg Rombach
IME Process Metallurgy and Metal Recycling, RWTH Aachen

1. INTRODUCTION

The importance of recycling as a constituent of the metal supply is undisputed. Apart from the economic and ecological advantages of the application of secondary raw materials there is a set of factors, which limit expenditure and use of recycling. These are among other things the metal contents of the raw materials, the emergence of secondary wastes, the multiplicity of alloys, a rising number of composite materials and the effects of user-specific material treatment on the attainable metal quality.

For the presented non-ferrous metals aluminium, copper and zinc, the recycling is to be evaluated very differently, due to substantial differences in areas of application, resulting quantities and process technology. None of these metals alone could give representative results for an optimal recycling quota for metals.

This article deals with today's and future recycling potentials, equally the limits of recycling are discussed. Here above all the availability and quality of secondary raw materials, as well as technological development of material processing and remelting and economic factors with their various effect connections are to be considered. Additionally, the evaluation of recycling concepts is made more difficult by the often misleading use of descriptive terms.

2. AVAILABILITY OF SECONDARY RAW MATERIALS

The supply of metal production with secondary raw materials is influenced by various parameters, which are described in the following by the example of aluminium. These are in particular aspects of time and quality that limit the availability of secondary material. An exact analysis of the existing metal flow and

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the used technologies leads to an additional problem in recycling, i.e., the definition of recycling quotas and recycled metal contents that are used to describe and evaluate recycling activities. This article introduces technical-metallurgically based solutions.

The difference between the produced and used aluminium quantity in Germany is substantial, as shown in the metal statistics. Questions arise as to how the high metal demand of the processing industry is covered and what role the recycling plays. According to figure 10-1 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 (WBMS, 1999). Indispuably, this leads to false conclusions.

For the correct definition of the terms of recycling, first 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. Therefore, aluminium materials have to be distinguished into two groups of alloys. With the cast alloys the content of alloying elements, above all silicon and copper, is rather high. In comparison, wrought alloys are lower alloyed, usually with magnesium and manganese. Therefore, they should be separated and, if possible, should arrive well-sorted in the recycling cycle. The material separation however is limited by application and collection. Figure 10-2 shows the German application of aluminium partitioned by casting and wrought alloys, which is dominated by the traffic sector (GDA, 1998). In each of these areas of application, with the exception of the packaging area, casting and wrought alloys which are often mixed, result after their use.

Looking at individual areas of application, a further distinction must be made: On the one hand closed loop recycling exists 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 for another use, usually in form of other alloys. Here in particular the secondary smelters (refiners) are mentioned, which produce cast alloys for the automobile industry, for example from a mixture of different old and new scraps.

Beside these idealised cases, a special area exists in regard to materials and distribution considerations. Wrought alloys are often converted to cast alloys and so achieve a materials modification. From a distribution standpoint, production scrap is not only internally used, but also externally and thus does not remain in a closed loop. Well-sorted wrought alloy scrap is recycled directly by the remelters into rolling and extrusion ingots, which then enter into both closed and open recycling loops. Mixed and contaminated scrap is recycled exclusively by the refiners into cast alloys and usually goes into open recycling loops (Rombach, 1998).

While the product is in use, the metal is considered to be material stock. The entire stock quantity for aluminium is estimated at 700 Million tonnes worldwide. The distribution of the metal concerns spatial, material and time-based aspects. The depot characteristics of aluminium can be described on the basis of selected products, product groups or sections or types of use (tab. 10-1). For packaging material for example, a high spatial variation exists with small product size and high distribution at the same time. The material purity can be high (menu plate, beverage can), middle (cover caps, painted foils) or low (multi-layer foils, vaporised coated bags). The retention time for aluminium packaging is small, with an average life time of half a year (Bauer, 2000).

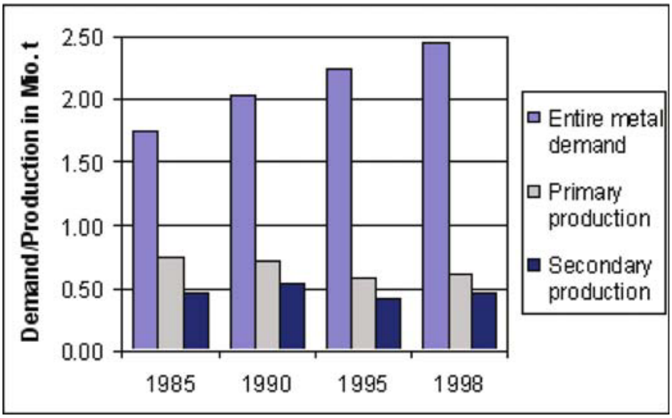


Figure 10-1. Development of entire metal demand, primary and secondary production of aluminium in Germany (WBMS, 1999).

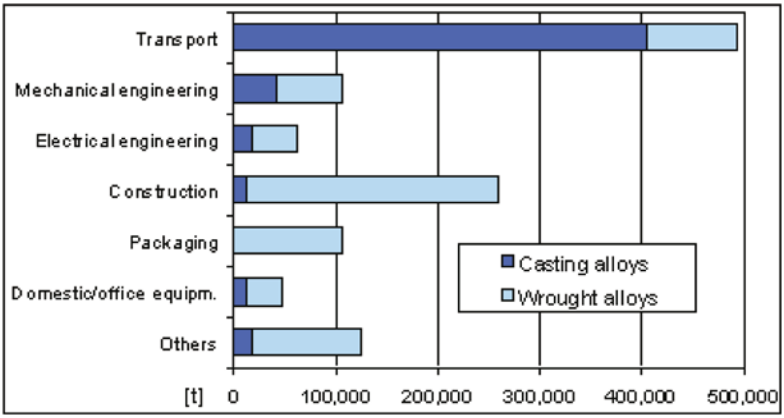


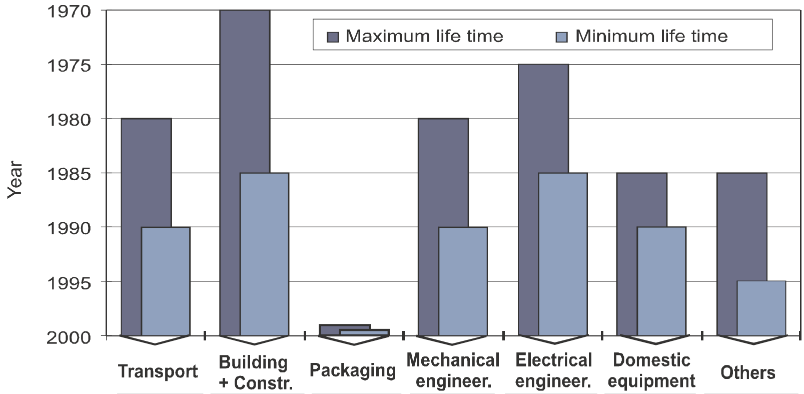
Figure 10-2. Use of aluminium casting and - wrought alloys 1997 (GDA, 1998).

Table 10-1. Depot characteristics of aluminium products in selected use areas (Bauer, 2000).

Depot characteristics		**Packaging**	**Transport** train/plane/car		**Construction**	**General engineering**	**Electrical engineering**
Spatial	Size	small	high	middle	high	middle	middle
	Distrib.	high	small	high	middle	middle	high
Materially	Purity	varied	high	small	high	middle	varied
Time-based	Retention time	small	high	middle	high	high	varied

The time-based aspect is illustrated in figure 10-3, which shows production periods, lifetime, recycling quotas, return flow quantities of aluminium scrap and the resulting difference to the present requirement in different applications. Today, for example, returned scrap from mechanical engineering applications, that were produced between 1980 and 1990 thus had a lifetime of 10 to 20 years. By the temporal shift of scrap return and production, the difference between scrap availability and metal demand increases. This is further expanded by the high growth rates in particular aluminium applications.

The determination of the scrap amount is based on the stock quantities of individual applications and their recycling quotas. The recycled metal content, i.e., the share of secondary material of products, resulting from this estimation would amount to 60% assuming total scrap collection. One reason for the difference to the actual value of 18%, specified previously, is the determination of the recycling quota. Following some definitions for metal recycling (Wolf 1999, Wolf 2000), the recycling quota consists in the collection quota and the technical recycling quota. This separation clarifies the different levels of the recycling and permits a resource-oriented view.



	Transport	Building + Constr.	Packaging	Mechanical engineer.	Electrical engineer.	Domestic equipment	Others
Recycling quota	85%	90%	65%	85%	85%	80%	50%
Return material after average life time	337,500 t	158,400 t	71,500 t	67,200 t	61,200 t	50,400 t	70,000 t
Surplus of momentary demand	235,000 t	120,000 t	35,000 t	58,000 t	2,000 t	40,000 t	60,000 t

Figure 10-3. Recycling quotas and return quantities for Germany, resulting from different lifetimes for different applications under the assumption of complete collection.

- The collection quota (CQ) determines the quantity of available secondary material that is registered in collection systems, related to the used product quantity.
- Technical recycling quota (RQt) represents the quantity of collected material that, after recycling, 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 again in two portions: the processing quota (PQ), which indicates how much metallic aluminium from the collection is supplied for melting and second the smelting yield (SY), which indicates how much aluminium is won as liquid metal. Also taken into account are the return flows from salt cake (SR) and dross treatment (DR), see fig. 10-4.

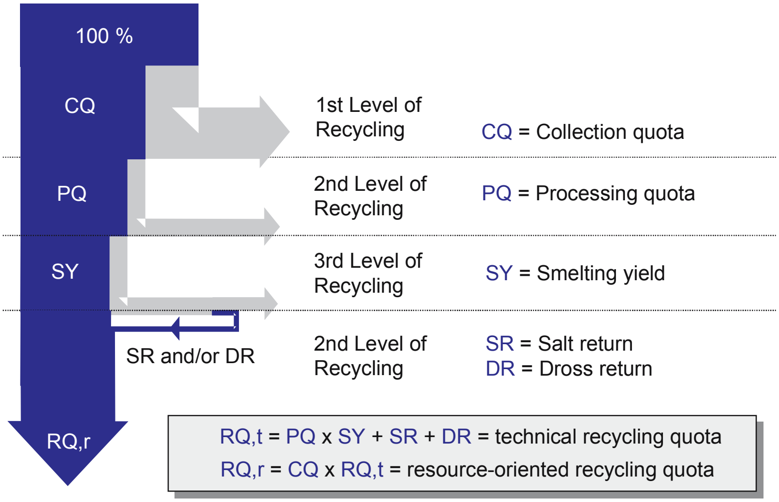


Figure 10-4. Definition of the recycling quotas for collection, processing and smelting (Wolf, 1999).

Using the example of German packaging recycling, the different levels can be illustrated. In 1997, consumption of light packaging material (LPM) consisting of plastics, tinplate, combined materials and aluminium, amounted to 1,778,198 t (Wolf, 2000). 1,582,596 t of the used packaging were collected, which corresponds to a collection quota of 89%. At the same time 389,525 t of non-packaging material were also collected. In the sorting plants plastics, tinplate and combined materials are separated and an aluminium fraction (LPM Al40) is supplied for further utilisation in mechanical processing, composite processing and pyrolysis. The appropriate recycling quota is calculated corresponding to figure 10-5. The technical recycling quota reaches values of 68,4% and the resource-oriented recycling quota

61,7%. For the different areas of aluminium use, the determined quotas vary significantly (Wolf, 2000). The range of collection quotas reaches from approx. 25% for the aluminium content of urban waste to almost 100% of the scrap quantity from the building sector (fig. 10-6). It hence becomes the crucial parameter for the success of a recycling concept regarding the most possible efficient utilisation of secondary raw materials.

Considering the collection of secondary raw materials in figure 10-3 accordingly, the theoretical recycled content decreases from 60 to 46%. Thus the recycling quota defines the retrievable metal content of the used materials or components.

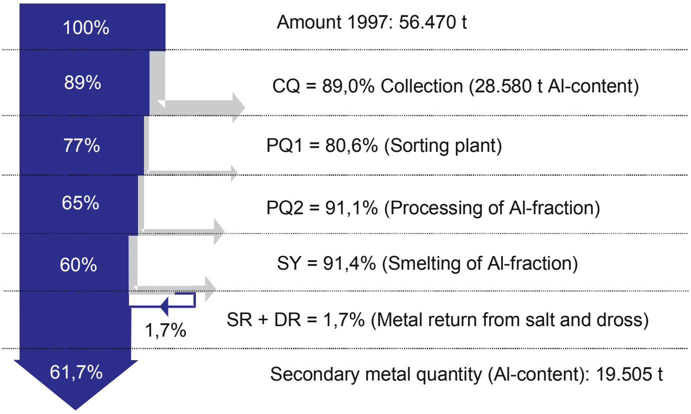


Figure 10-5. Determination of the recycling quotas for aluminium light packaging material (Wolf, 2000).

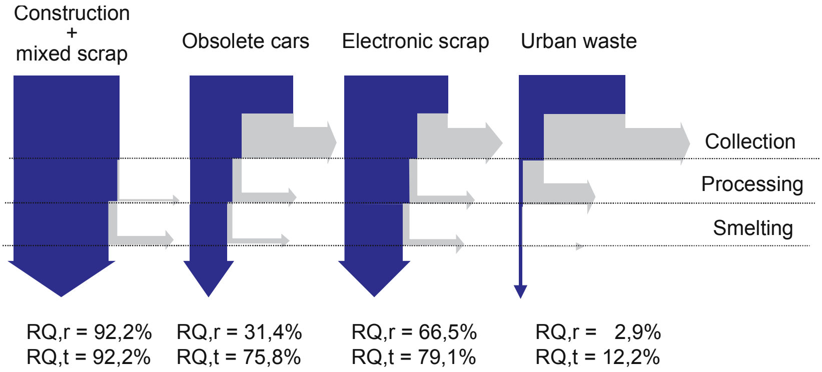


Figure 10-6. Technical and resource-oriented recycling quotas for aluminium products (Wolf, 2000).

In contrast to the resource-oriented recycling quota, the recycled metal content of a given product is the share of secondary metal that is used for processing. The recycled metal content usually lies below the recycling quota, since with rising application more primary metal must be produced than corresponds to the losses during the use phase. However, the recycled metal content is unsuitable as a standard of valuation for recycling success, since it represents a regional value, which can be misinterpreted depending on the existing open scrap market and the rising metal demand.

3. QUALITY INFLUENCE OF SECONDARY RAW MATERIALS ON THE RECYCLING

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

Aluminium:

Refining of aluminium is only possible within very small limits (table 10-2). Elements such as iron, manganese, silicon, magnesium, copper and zinc remain predominantly dissolved or precipitated in the metal phase. For this reason, during primary aluminium production the refining is done before reduction. For recycling, this means an exact separation of the scrap before melting with regard to type of alloy and purity. If not, only a dilution with primary metal or blending of different melts remains as a possibility for alloy adjustment.

Table 10-2. Possible melt treatment of aluminium

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
Inter-metallic 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

As a consequence, two furnace types became generally accepted. Well-sorted scrap and new scrap are usually melted in large volume reverberatory furnaces, whereas mixed new and old scrap, dross and turnings are melted in smaller, flexible salt bath rotary furnaces. Despite rising return quantities from production and use, the intensified recycling of wrought alloy scraps at the remelters cause a lack of blending material for the refiners. Their operations are thus becoming more costly through the necessarily increased use of primary metal. Accordingly, the scrap input of the German aluminium refiners (fig. 10-7) shows decreasing shares of new scrap in the years 1975–1999, while the share of old scrap increased (VDS, 2000).

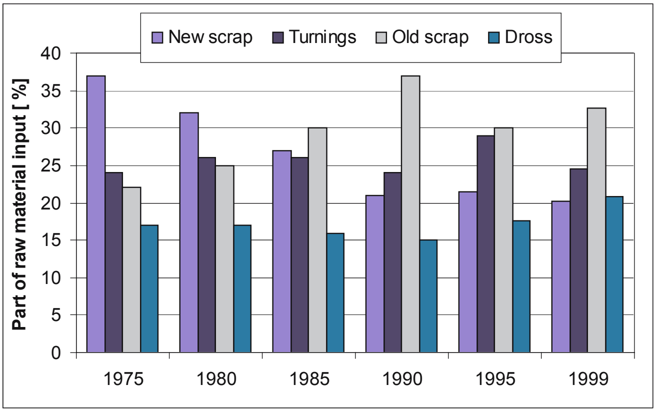


Figure 10-7. Development of the scrap supply of the German refiners from 1975 to 1999 (VDS, 2000).

For aluminium, the scrap balance of 1997 in figure 10-8 clarifies the aspects of scrap availability. First a small export surplus is detectable that consists of old scrap, processing scrap and turnings. For secondary aluminium production about 400,000 t scrap (Al-content) were used, of which about 70,000 t well-sorted wrought alloys were remelted. Further wrought alloys were remelted in the casthouses of the primary smelters (174,900 t) and the semi-finishing plants (190,000 t) (BAW 1998, BAW 1999). The amount of production scrap of 920,000 t was directly reused in the semi-finishing manufacturing as cycle material and was thus not registered statistically. With regard to the shown scrap use, the imported quantity of 168,000 t secondary aluminium and the scrap share of foreign primary metal the real recycled metal content of total German production results to 37%. This is a material balanced average value of the individual areas of application.

The interaction among product areas can be quantified by the existing scrap flows (fig. 10-9). An alloy cascade results, where the recycling activities increase the alloy content of the entire stock. Unalloyed aluminium forms the starting point of this material flow and therefore has the smallest recycled content. Lowering of the alloy status, i.e., a reversal of the usual supplying direction into figure 10-9 is only possible with expenditures comparable to the primary metal production.

Finally, the success of recycling activities can only be evaluated by the metal quantity recovered and thus by primary metal savings in the total aluminium system. It has to be considered that aluminium recycling needs only about 10% of the energy expenditure of the primary smelting. Beyond that, well-sorted collection and special processing work against an enrichment of alloying elements in the recycling cycle and thus promote the maximal utilisation of secondary raw materials.

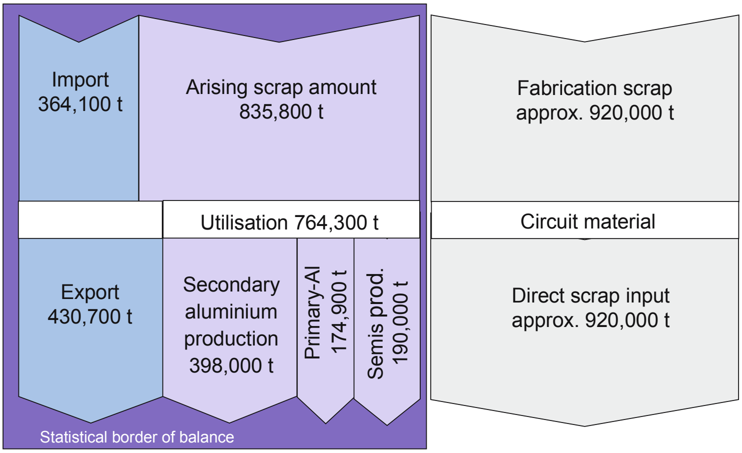


Figure 10-8. German scrap balance 1997 (BAW 1998, BAW 1999).

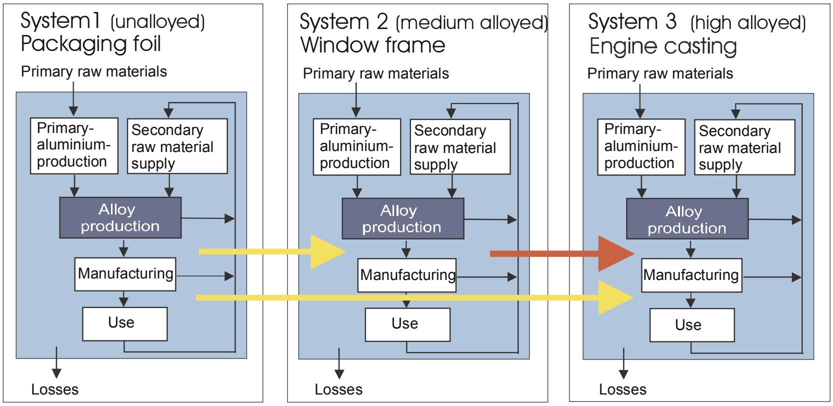


Figure 10-9. Interaction among aluminium recycling systems.

Copper:

For the metal supply of the copper-processing industry in Germany, of 1.14 million t in 1998, a similar import dependency results as for aluminium, however the secondary production with 370,000 t was already situated above the primary production (320,000 t), which also uses large quantities of secondary raw materials (WBMS, 1999). The recycled metal content of the German total production amounts to 51%.

The recycling of copper can take place in purely secondary smelters as well as in primary smelters, where the process steps and intermediate products are similar or the same. The scrap is differentiated into metallic copper and copper alloys and raw materials with non-metallic copper contents. Metallic raw materials of secondary copper smelting are pure and high copper-bearing scrap as well as copper/iron combined materials. Slag, ash and copper-bearing sludge from galvanising (with copper contents under 30%) are non-metallic secondary raw materials. Depending on its copper content, mechanical characteristics and chemical composition, secondary raw material is inserted into different process levels (fig. 10-10). Only about 28% of the feed materials are non-metallic or oxidic and must be reduced in the blast furnace with a high coke consumption.

After the final electrolytic refining, the quality of secondary copper is identical to the primary metal, so that a direct substitution of primary raw materials is achieved. This is important because the energy demand for primary and secondary smelting (for a representative mixture of raw materials) with 21.8 respective 20.5 GJ/t copper cathode is almost equal, but additionally, copper mining requires 35 GJ/t copper content in the concentrate, due to the low ore content (Bruch, 1995).

Copper fulfils the preconditions to reach high recycling quotas much more easily than aluminium or zinc, since it is used mainly in pure metallic form, e.g., in wires and pipes. Likewise, the most important alloys brass and bronze can be remelted in pure form. Beyond that, the electro-chemically noble character of copper and the associated excellent refining conditions enable a recovery from very low copper bearing raw materials with a high metal yield.

Zinc usually returns in the recycling cycle indirectly, since it is used mainly as an alloying element (brass) or as a coating on structural steel. Only about 22% of zinc production is converted to semi-finished material or castings (tab.10-3) (ILZSG, 2000). Beyond that, zinc is consumed as active corrosion protection or chemicals and cannot be recovered from these applications.

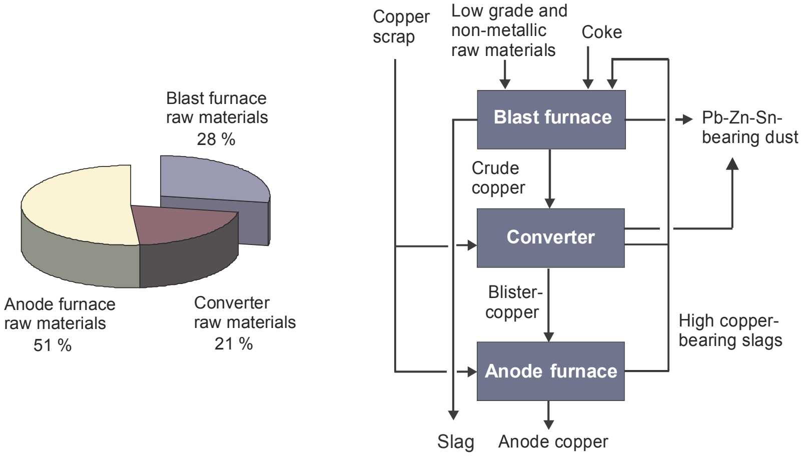


Figure 10-10. Raw material distribution on the process levels of the secondary copper production.

Table 10-3. End use of zinc (ILZSG, 2000)

Application	Share
Galvanising	47 %
Brass alloying	19 %
Zinc alloys	14 %
Semi-finished products	8 %
Chemicals	9 %

Altogether, the recycled metal content of the world-wide production amounts to 18% due to the discussed applications. In Germany the share of recycled material of 49% is clearly higher, 21% of the primary zinc production alone originates from secondary raw materials. This is achieved to a large extent by the use of the so-called Waelz oxide from the processing of steel plant filter dust in the hydrometallurgical zinc production (fig. 10-11). On the other hand, the different ways of zinc recycling are difficult to compare because of the different products. Only New Jersey Refining and electrolysis can produce Super High Grade quality (SHG >99.995% Zn). Besides that, lower metal qualities like cadmium free zinc (98.5% Zn), zinc dust or zinc oxide are produced.

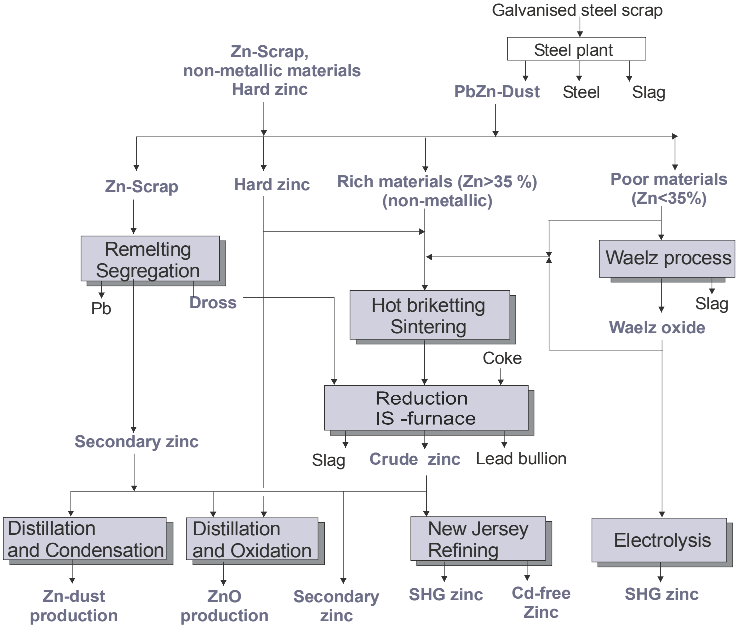


Figure 10-11. Process scheme of the secondary zinc production.

4. TECHNOLOGICAL DEVELOPMENT

By the example of aluminium packaging, the potential for technological development, particularly resulting from interactions of processing and smelting, can be clarified. Figure 10-12 shows the existing system of light packaging recycling. The aluminium fraction from the sorting plants, with 40% aluminium content and predominantly organic remainder, cannot be remelted. Combining 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. By the application of fully automated sorting plants, the metal yield of material processing could increase from 80.6 to 94.0%. Then the process-specific energy consumption increases, but related to the larger product quantity, this turns into an advantage.

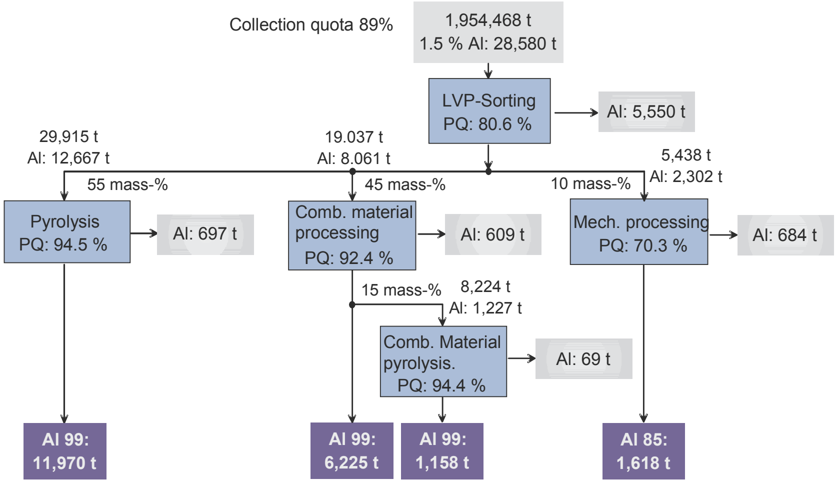


Figure 10-12. Processing of the Al-fraction of light packaging material (SFB, 2000).

Scenario calculations show that in the case of appropriate smelting techniques for the future recycling concept NT (exclusively newest technology) and its possible implementation in the year 2010, saving potentials of 2,000 respective 1,370 MJ/t of produced alloy results, with an increase of the aluminium quantity around 20, respectively 4% (fig. 10-13) (SFB 2000, Rombach 2001).

The energy requirement limits a further increase of the processing quota above 90% (fig. 10-14), due to additional processing steps necessary for sorting remainders and wastes.

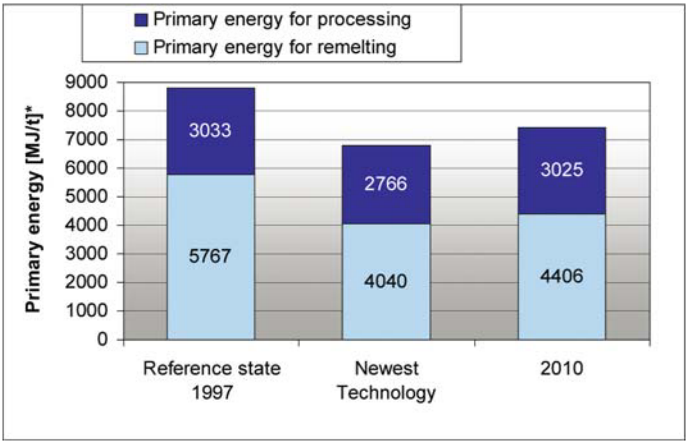


Figure 10-13. Comparison of the primary energy demand of today's and of possible future concepts of light packaging recycling (*without Al-recovery from salt slag and dross)(SFB 2000, Rombach 2001).

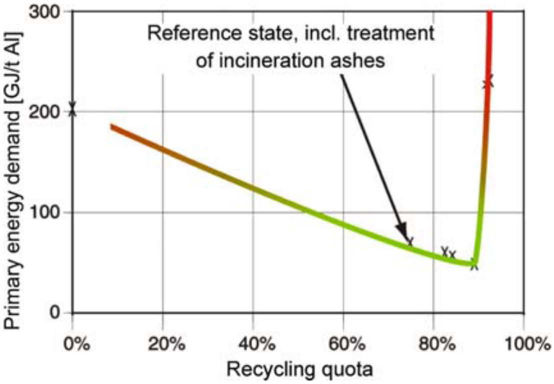


Figure 10-14. Primary energy requirement as a function of the recycling quota for the example of aluminium in light packaging (SFB, 2000).

However, further questions about the limits of recycling arise, also for the other metals. Is the high expenditure for the handling of certain materials also in correct relation to the obtained result concerning emissions and wastes? Is it meaningful to close material cycles at any price? Such questions cannot be answered generally but clarify the demonstrated necessity for a differentiated view of the respective production lines.

5. LIMITS OF ECONOMIC UTILISATION

The economy of metal recycling is determined by the difference between the scrap price and the attainable selling price of the different secondary alloys. The price for secondary alloys is subjected to many influences, e.g. the availability of certain kinds of scrap on the production level and in particular the competitive situation on the consumer level. The price calculation for scrap is at the moment still based on standardised cast alloys, i.e., on the product properties. Here certain deductions depending upon metal content, alloy and impurity degree are made. Due to the large number of cast alloys concerned and company-specific requirements, the indicated price for the cast alloys can be regarded at best as reference value (Krone, 2000).

Table 10-4. Prices for aluminium alloys and scraps, March 2001 (VDM, 2001)

Kind of metal or scrap	Price [€/100kg]		
Aluminium-alloy 231 G AlSi12(Cu)	190	to	195
Aluminium-alloy 226 G AlSi9Cu3	175	to	180
Primary metal 99.7 standard-ingots (EU declared)	170	to	175
Pure aluminium wire scrap	140	to	145
Aluminium extrusion scrap	140	to	145
New alloy scrap (low copper)	95	to	100
Aluminium casting scrap	70	to	75
Aluminium turnings	75	to	80

The price development in the period of 1993–1996 for pure aluminium scrap and casting scrap as well as primary aluminium, silicon and copper-bearing cast alloys (fig. 10-15) shows the common trend, i.e., the relatively constant difference of the prices for scraps and alloys (OEA, 1998).

Even if the prices for pure aluminium (Al 99.8) and pure aluminium scrap behave similarly, they are nevertheless subjected to stronger fluctuations.

Since the costs of the recycling are mainly independent of the metal price, they control the yield. Additionally, the yield depends on the quality of the secondary raw materials (fig. 10-16). If the quality is high, the scrap purchase price is also high, but compared to low-grade raw materials returns can be increased due to the small processing and remelting costs. A scrap depot is thus exploited, in order to maximise the present difference between entire production costs and the anticipated selling price.

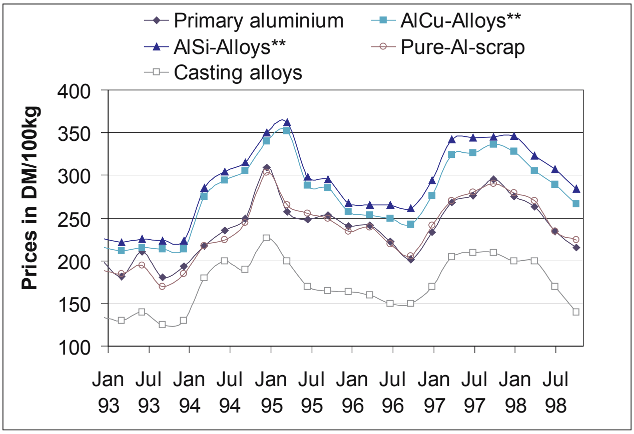


Figure 10-15. Price comparison among pure aluminium, silicon and copper bearing alloys as well as scrap from pure aluminium and casting from 1993 to 1998 (*LME-Cash quotation for duty-free commodity **Small quantities to 3 t) (OEA, 1998).

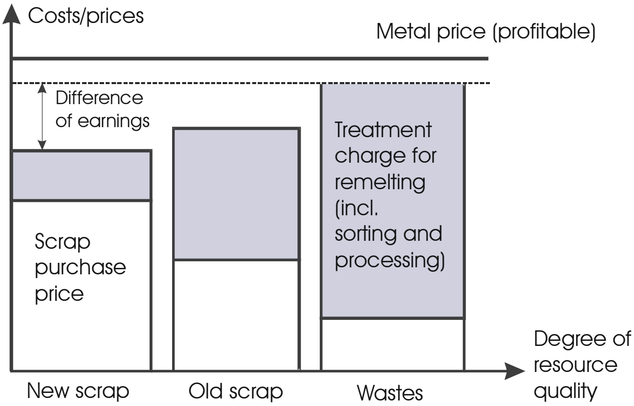


Figure 10-16. Connection between scrap price, remelting costs and difference yield for different scraps (Bomsel, 1992).

For the secondary smelters the price limit of the metal scrap is governed by its utility value during the metallurgical process (fig. 10-17). This again depends linearly on the metal price and beyond that on the condition of the raw material, the plant utilisation and the technical parameters of the process. Falling metal prices finally, when achieving the price limit, lead again to larger inventories.

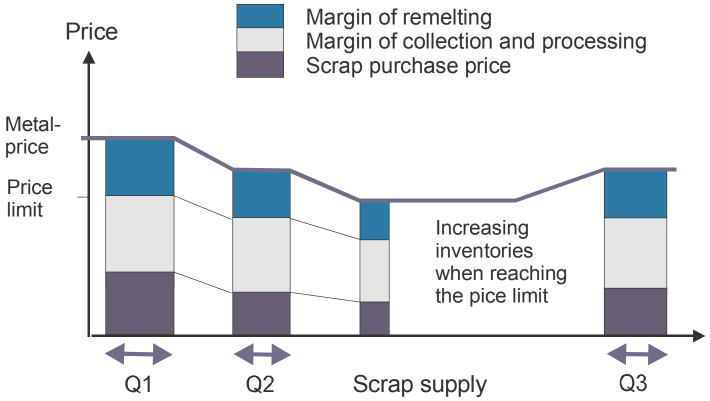


Figure 10-17. Metal price and stock behaviour (Bomsel, 1992).

The remelter is interested in getting as precise information as possible about the composition of the scrap in order to limit the risks of the price calculation. On the other hand, the scrap metal dealer sells his product to that secondary smelter, for which it has the highest utilisation value. He must consequently guarantee the quality of the raw materials, which results in the necessity for a stronger differentiation during scrap collection or the investment in processing and sorting equipment.

Not considering the obtained and possible productivity increases of collection and material processing, at a certain point the utilisation value of secondary raw materials becomes too low to cover these costs. For some residues and low-grade wastes, e.g., steel plant dust, this point has already been achieved. Here the question arises of how the costs of such a subsidised recycling concept are to be carried (Bomsel, 1992).

From this point of view, limits of metal content in the secondary raw materials can be derived for the discussed metals (table 10-5). Following the price calculation for ore concentrates, the calculations are based on the value of the receivable metal content. Beyond that, additional payments for the treatment of low-grade metal-bearing wastes, which enable the recycling of such raw materials are considered.

Table 10-5: Limiting metal contents of economic utilisation for aluminium, copper and zinc-bearing secondary raw materials. (Metal price basis, 5/2000)

Al	50 % Al (without processing) Metal content (gainable after deduction of melt loss): 40 % Metal value: 450 €/t material Treatment charge: 350-700 €/t material
Cu	1. 2 % Cu, Metal value: 40 €/t material + 100 €/t disposal charge 2. 3 % Cu, (10 ppm Au, 50 ppm Ag) Metal value (loss-free): 55+80+10 = 145 €/t material 3. 7,5% Cu, Metal value: 145 €/t material Treatment charge: 130 €/t material Refining charge : (130 €/t copper) 5 - 10 €/t material total 135 - 140 €/t material
Zn	Oxidic raw materials: 23% Zn (+ Pb), Metal value after deduction of melt loss : 260 DM/t material + 100 DM/t additional payment (prorated) = 155 €/t material Waelz Charge : 130 €/t Material Refining charge: (255 €/t Metall) 30 €/t Material total 160 €/t Material

6. SUMMARY

This work points out different limits for the metal recycling of aluminium, copper and zinc. Being the most important parameter of the recycling activities of every metal, the scrap availability is focused on by the discussion. Knowing the availability of secondary raw materials in an existing system, the respective recycled metal content of production can be determined. However, this varies regionally, temporally and product and metal-specificity. 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 itself can be described by metal yield and energy consumption. For both the recycled metal content and the recycling quota, the quality of the raw material, i.e., the conditions at production and use, the alloying elements and the metal content have to be considered. Finally, the treatment costs of secondary raw materials limit the recycling, which are again influenced by metal price, metal contents and quality.

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