23/2017
Warrings, R.; Fellner, J. (2017) „Where aluminum household goods get lost – gaps on the way to a circular economy" In: CD-Proceedings Sardinia 2017, 16th International Waste Management and Landfill Symposium "Sardinia Symposium 30th Anniversary Book", 2-6 Oct. 2017, S. Margherita di Pula (Cagliari), Sardinia, Ed.: Cossu, R.; Stegmann, R., CISA Publisher, Sardina, paper 302, p 1-12, ISSN 2282-0027, ISBN 978-88-6265-010-6

WHERE ALUMINUM HOUSEHOLD GOODS GET LOST – GAPS ON THE WAY TO A CIRCULAR ECONOMY

R. WARRINGS*, J. FELLNER*

**Vienna University of Technology, Christian Doppler Laboratory for Anthropogenic resources, Institute for Water Quality, Resources and Waste Management, Karlsplatz 13/226, A-1040 Vienna, Austria*

SUMMARY: Aluminium (Al) represents the metal with the highest consumption growth in the last decades. Beside it increasing usage in the transport (light weight construction of vehicles) and building sector, Al is ever more used for household goods like packaging material, which represents due to is short life a readily available source for secondary aluminum.

The present paper investigated to which extent this potential source for Al is already utilized in Austria and highlights areas for future improvements. Thereto a detailed material flow analysis for Al used in packaging & non-packaging household goods in 2013 was conducted. In practice all Al flows starting from market entrance through waste collection and processing until its final recycling or disposal have been investigated. The results of analyses indicate that about 27,700 t/a (3.3 kg/cap/a) of Al packaging & non-packaging arose as waste. At present about 12,500 t/a or 45% are recycled as secondary Al. The vast majority thereof originates from separate collection of rigid packaging, like beverage cans (58%). The remaining quantity of Al was recovered from other collected Al (13%), waste incineration bottom ash (22%) and MBT plants (7%). At the same time, a significant amount of Al was lost in thermal waste treatment due to oxidation (11%) and due to insufficient recovery of Al from waste incineration bottom ash and MSW treated in mechanical biological treatment (MBT/MT) plants (42%).

1. INTRODUCTION

The world's population keeps growing, and so does its demand for goods of all kinds. The increasing fear of shortage or unavailability of raw materials from natural sources and the unanswered questions how to handle the severe impacts on the environment from incessant production are huge challenges in the 21st century (RLI, 2015). The scarcity of raw materials is especially delicate in countries (and communities like the European Union) which are highly dependent on imports of commodities (OECD, 2015).

Changing the way of use from a linear (take, make, use, dispose) to a more integrated pattern, where the consumption of raw material is reduced and the re-use of existing goods is encouraged could be an important step to meet these challenges (EAA, 2016). The latter describes the concept of Circular Economy. While there is no uniform definition of Circular Economy, all do have the same bottom-line: "the objective of the circular economy is to preserve the value of utilized resources and materials as long as possible, to use them as frequently as possible, and to produce as little waste as possible (ideally none at all)" (Wilts, 2016). The European Energy Agency adds that Circular Economy has "a positive, solutions-

Proceedings Sardinia 2017 / Sixteenth International Waste Management and Landfill Symposium/ 2 - 6 October 2017
S. Margherita di Pula, Cagliari, Italy / © 2017 by CISA Publisher, Italy

based perspective for achieving economic development within increasing environmental constraints" (EAA, 2016). The European Commission introduced an ambitious "EU Action Plan for the Circular Economy" and released various legislative proposals like the "Proposed Directive on Packaging and Packaging Waste" which claims that 65% of all packaging waste should be reused and recycled by the end of 2025, resp. 75% by 2030 (EC, 2015).

The packaging sector in Austria produces around 1.3 million tons of packaging waste p.a. (which is equivalent to more than 30% of Municipal Solid Waste (MSW) generation) (BMLFUW, 2017), while contributing only 1% to the gross national product (PROPAK, 2017).

One of the frequently used packaging materials is Al, due to its versatility and outstanding properties. It serves as a barrier against light, fluids, oxygen, microorganisms and other substances, prevents flavor or scent impairments, and ensures durability. Packaging has usually short life cycles and requires therefore constant reproduction of packaging materials.

In order to gain primary aluminum, the raw material has to be extracted from Bauxite in an energy-intensive process. Using Aluminum as secondary instead of primary raw material through recycled and re-melted Aluminum scrap can reduce the energy input by 90-95%. The mining of Bauxite has also severe impacts on local and global ecology because large extraction areas are situated in tropical rainforests and the lagged behind red mud can lead to environmental damage. Furthermore dependency on imports, price volatilities and insecurities of supply caused by geopolitical factors have to be considered (Rüttinger, Treimer, Tiess, & Griestop, 2016; Wilts, 2016).

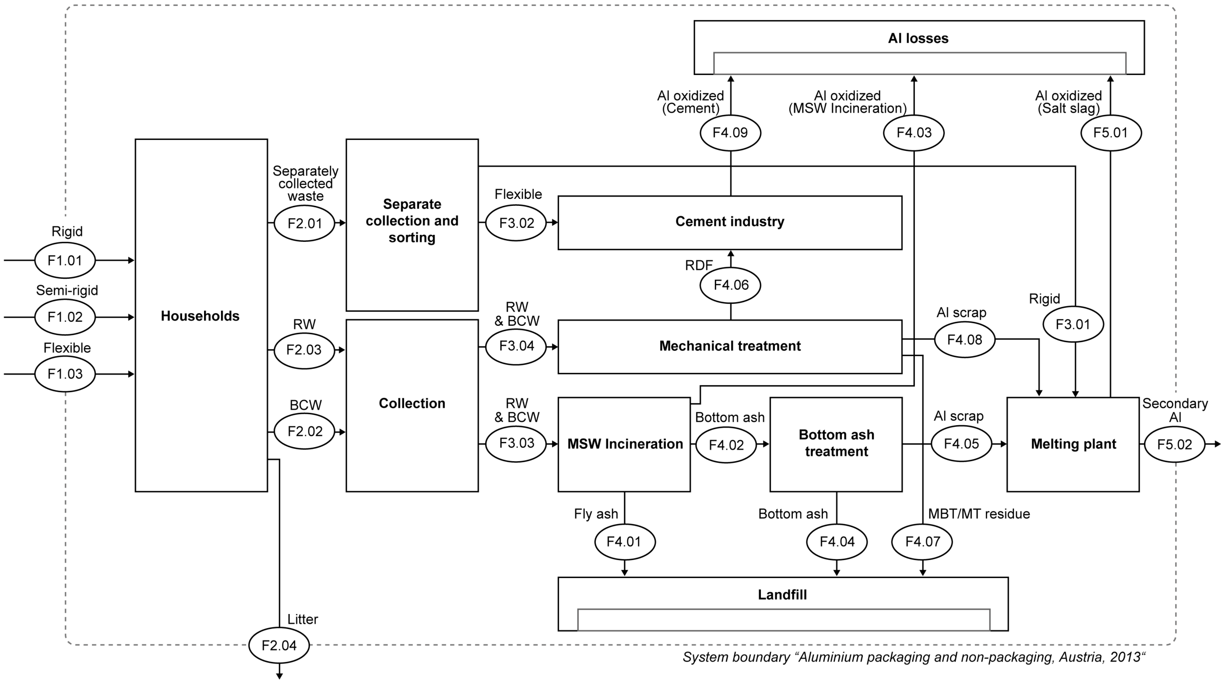
The environmental, political and economic impacts associated with the production of Al packaging could promote the use of secondary Al, which requires that recycling rates are optimized and losses in the recycling chain minimized (Aludium, 2017; Bühler, 2017). The minimum targets for reuse and recycling regarding Al contained in packaging waste by the "Proposed Directive on Packaging and Packaging Waste" are set to 75% till the end of 2025 and 85% till the end of 2030 (EC, 2015). For Austria this requires also an adjustment of the Austrian Packaging Ordinance 2014 (Verpackungsverordnung, VVO), which specifies a minimum recycling rate of 50% for metals (Republik Österreich, 2014).

This paper aims to analyze the current status of aluminum management in Austria and to identity potentials for improvement with respect to the implementation of a circular economy, as required by the European Commission.

2. MATERIAL AND METHODS

In this study the method of Material Flow Analysis (MFA) is used to capture, describe and investigate the physical flows (Brunner & Rechberger, 2017) of Al packaging & non-packaging household goods in Austria for 2013. The presented material flow model delineates the different stages of waste management (collection, sorting, treatment and disposal) and the recycling process itself (re-melting) (see Figure 1). In practice, the following processes are considered:

- Households (as waste generators)
- Waste Collection and Sorting
- Waste Incineration and Bottom Ash Treatment
- Mechanical Treatment
- Industrial Incineration (cement industry)
- Aluminum smelter



BCW ... bulky & commercial waste
MSW ... municipal solid waste
RDF ... refuse derived fuel
MBT ... mechanical biological treatment
RW ... residual waste

Figure 1. Model overview of Al packaging & non-packaging in Austria, 2013

2.1 Data collection

The input flows F1.01-F1.03 describe the amount of used and disposed Al in Austrian households in 2013. Different fractions were distinguished (beverage cans, beverage cartons, composite foils and other packaging & non-packaging) and allocated to rigid, semi-rigid and flexible packaging & non-packaging. Al is fed into separate collection systems or disposed into residual waste (RW) (or occasionally into bulky and commercial waste). Besides Al packaging also non-packaging Al was considered if collected via RW. This non-packaging Al includes household foil or other non-packaging, like household ware, fittings, tubes, coins, or coffee capsules. For the determination of the figures evaluations on market volume and waste quantities, primarily of residual waste were carried out (ARA, 2017; TB Hauer, A.C. Nielsen, & ÖIV, 2015). Because of the short lifetime of packaging, a general assumption was made that waste generation equals the market volume of packaging and that no stock piling or losses through littering occurred. Littering (F2.04) was neglected, because intensive and regularly repeated clean-up work by municipalities (Loimayr, 2010) and retained solids at the river power stations of the Danube complement common waste collection systems and prevent permanent losses (Verbund AG, 2017).

Beverage cans and beverage cartons were calculated by market volume from data of Austria's leading packaging compliance scheme ARA (2017, Altstoff Recycling Austria) and a survey on packaging by TB Hauer et al. (2015). According to a residual waste analysis in Vienna in 2015 not all beverage cartons contain Al foil (ARGE TBH, FHA, & pulswerk, 2016), whereby for the corresponding an average Al content was assumed (FKN, 2017).

It was difficult to identify the market volume of Al foils used as mono material or in composite packaging in Austria, because no specific data were available. Al used as foil can be allocated to the Al or composite material fraction and overlaps are inevitable. If foil is used as mono material or detectable dominant aluminum in compounds these fractions are part of the Al balance, otherwise allocated to composite materials and missed in the Al account. The calculated data of Al in composite foils relied on a survey of product related MFA of RW in Vienna (Produktbezogene Stoffflussanalyse von Abfällen in der Wiener Restmüllanalyse, ProSFA) from Taverna, Frühwirth, and Skutan (2010). These data were compared with a Spanish study by López, Román, García-Díaz, and Alguacil (2015) and estimates from the European Aluminium Association (EAA, 2017) and the European Aluminium Foil Association (EAFA, 2017). The figures from the representatives of the Al industry are based on production/market volume and not like the others on waste analyses. The allocation within Europe and the type of usage, e.g. for household foil was not clear and therefore an accurate amount of Al foil for Austria could not be presumed.

The volume of other packaging (all other fractions but beverage cans, beverage cartons and composite foil) in residual waste was estimated through different waste analyses (Amt der Kärntner Landesregierung (Ed.), 2012; ARGE Abfallanalyse Oberösterreich 2013, 2014; ARGE TBH et al., 2016; Boku, 2011; IUT & SDAG, 2014; Land Salzburg, 2013; Salzmann Ingenieurbüro, 2000; TB Hauer et al., 2015; TBU, 2010). A big part of the non-packaging fraction was the packaging similar household foil (F1.05) (TB Hauer et al., 2015).

The material behavior of different types of Al packaging & non-packaging materials in combustion and re-melting processes depend on the thickness, mechanical resistance and the Al alloy (Biganzoli, Gorla, Nessi, & Grosso, 2012), especially concerning the oxidation process during incineration. For this reason, the flows have been assessed and classified in flexible, semi-rigid and rigid packaging & non-packaging fractions. Rigid packaging are beverage and food cans or aerosol containers, rigid non-packaging e.g. household ware, fittings, coins etc., all determined by a wall thickness above 0.2 mm. Semi-rigid Al has a wall thickness of 0.05-0.2 mm, packaging material are closures, tubes or trays while non-packaging are e.g. tubes or hosts. Flexible packaging are foil and laminated foil, while flexible non-packaging are e.g. the packaging similar household foil with foils no thicker than 0.05 mm (ARGE TBH et al., 2016; López et al., 2015). Al packaging is mostly manufactured of rolled products, hence foils and sheets. The description foil has a broader meaning and thus semi-rigid and rigid packaging can be made of foil as well (Lamberti & Escher, 2007). In this work's context, foil is determined as flexible packaging & non-packaging through the thickness of the material, used in multi-layer composite material or as mono material like butter or chocolate wrapping.

The detailed ProSFA survey on Al in residual waste opened the possibility to create transfer coefficients for the different types of packaging & non-packaging material (flexible, semi-rigid, and rigid) and allowed to trace the impact on the materials in different processes.

Collection systems separate beverage cans, beverage cartons and other Al packaging & non-packaging (F2.01), the rest ends up as residual waste in MSW (F2.01). The residual waste is further processed, in the first stage of the treatment, the residual waste from households and similar institutional waste undergoes thermal (F3.03) or biotechnological treatment (F3.04) (BMLFUW, 2014, 2015). In the combustion process, Al is partially removed with fly ash (F4.01) (Wien Energie, 2012) from combustion (F4.02). The Al (partly) oxidizes during the combustion process, which extents define the loss of the recoverable Al (F4.03). It is difficult to define the level of oxidation and not many extensive studies addressing this topic have been made (Biganzoli et al., 2012; Hu, Bakker, & De Heij, 2011; López et al., 2015). Biganzoli et al. (2012) realized the most practicable experiments "in a full-scale waste to energy plant during standard operation" and their results are the foundation for calculations of oxidation rates.

The solid residues from combustion, slag or bottom ash are handled with magnetic separators to depart iron and with eddy current separators to separate non-ferrous metals from other material. The current technology in Austria allows detecting Al lumps larger than 3-4mm, while smaller ones remain in the bottom ash and are thus landfilled. There are eleven incineration plants for MSW in Austria with significant differences in capturing achievements through the connected separation or sorting plants, whereof some do not detect non-ferrous metals at all. Data are only particularly available and many incineration plants have heterogeneous waste inputs with divergent waste compositions. The incineration plants in Vienna burn nearly exclusively RW and maintain precise data recording. The processing technique of the bottom ash from these Waste-to-Energy (WtE) plants can be taken as average for Austria and the corresponding Al metal transfer ratios served as reference value for treated bottom ash within Austria (Stadt Wien MA 48, 2017). The recovered Al is fed back as Al scrap (F4.05) into the re-melting process while the residual bottom ash is landfilled (F4.04).

The recovery of Al as Al scrap (F4.08) from mechanical treatment relied on information given by the operators of mechanical-biological treatment plants (MBT/MT). The outputs from MBT/MT go into industrial incineration (4.06) and landfill (F4.07). The first are primarily used in the cement industry and are lost for Al recovery (F4.09).

The recovered Al scrap from collected packaging & non-packaging (F3.01), MBT/MT treatment (F4.08) and bottom ash (F4.05) is fed into melting plants. During the re-melting process minor losses occur due to further oxidation (Fragner, 2017), furthermore the Al scrap is seldom free of adhesions which lessens the Al content of the fed material and results in higher general losses during the re-melting process (F5.01). The Al regained from the re-melting process is led back into the circulatory Al system as secondary Al (F5.02) and reflects the recycled volume of Al packaging.

2.2 MFA and data characterization

The data on material flows in this study are based on various data sources, which again are based on different reporting methods. A characterization of the data uncertainty was conducted in order to evaluate the robustness of the Al flows and model results. For the quantitative data, mean values and uncertainties (given by standard deviation) were calculated, whereby for the latter a normal distribution was assumed. To evaluate the data and assess the resulting uncertainties a rating scheme with assigned coefficients for various indicators, introduced by Laner, Feketitsch, Rechberger, and Fellner (2016) had been applied (see Table 2). Their approach goes back to a data quality assessment scheme introduced by Weidema and Wesnæs (1996) and a data uncertainty assessment of material flows using data classification from Sörme and Hedbrant (2001). In practice five data quality indicators (reliability, completeness, temporal correlation, geographical correlation and other correlation) were rated on a scoring system from 1 to 4 (see Table 1 and 2), with 1 ranking the highest (good quality data) and 4 the lowest (poor quality data). The indicator reliability refers to the methodology of the data generation and how well the data were documented and verified. Completeness evaluates all relevant mass flows in question and assesses the extensiveness of the data. Temporal and geographical correlations refer to the consistency and deviation of the data for time and space. The other correlation indicates values related to a different product or technology. Sometimes information relies on expert judgements, with the reliability of the expert's opinion as only indicator (Laner et al., 2016). The uncertainties were quantified by coefficients of variation (CV, standard deviation divided by mean). The aggregating individual CV's built the overall uncertainty of the data.

As executing software, STAN (substance flow analysis) was chosen to secure the input data of the MFA regarding uncertainties and inconsistent data. The inherent Sankey diagram displays the thickness of the data flows proportional to their value (Cencic & Rechberger, 2008).

Table 1. Data quality indicators and assessment criteria (Laner et al., 2016)

Indicator	Score: 1	Score: 2	Score: 3	Score: 4
Reliability	Methodology of data generation well documented and consistent, peer-reviewed data.	Methodology of data generation is described, but not fully transparent; no verification.	Methodology not comprehensively described, but principle of data generation is clear; no verification.	Methodology of data generation unknown, no documentation available.
Completeness	Value includes all relevant processes/flows in question.	Value includes quantitatively main processes/flows in question.	Value includes partial important processes/flows, certainty of data gaps.	Only fragmented data available; important processes/mass flows are missing.
Temporal correlation	Value relates to the right time	Deviation of value 1–5 years.	Deviation of value 5–10 years.	Deviation more than 10 years.
Geographical correlation	Value relates to the studied region.	Value relates to similar socio-economical region (GDP, consumption pattern).	Socio-economically slightly different region.	Socio-economically very different region.
Other correlation	Value relates to the same product, the same technology, etc.	Values relate to similar technology, products, etc.	Values deviate from technology/product of interest, but rough correlations can be established based on experience or data.	Values deviate strongly from technology/product of interest, with correlations being vague and speculative.
Expert estimate	Formal expert elicitation with (empirical) database—transparent procedure and fully informed experts on the subject.	Structured expert estimate with some empirical data available or using transparent procedure with informed experts.	Expert estimates with limited documentation and without empirical data available.	Educated guess based on speculative or unverifiable assumptions.

Table 2. Coefficients of variation for the data quality indicators (Laner et al., 2016)

Data quality indicator	Sensitivity level	Score: 1	Score: 2	Score: 3	Score: 4
		Coefficient of variation (CV, in %)			
Reliability	–	2.3	6.8	20.6	62.3
Completeness/temporal/geographic/other correlation	High	0.0	4.5	13.7	41.3
	Medium	0.0	2.3	6.8	20.6
	Low	0.0	1.1	3.4	10.3
Expert estimate	–	4.5	13.7	41.3	124.6

3. RESULTS

The results of the MFA are presented in Figure 2. The market volume of Al packaging & non-packaging was an estimated 27,700 tons according to a survey on packaging volume in Austria 2013 (TB Hauer et al., 2015) and residual waste analyses on Al non-packaging. This figure is made up of 18,300 tons of Al found in residual and bulky waste plus 9,400 tons of separately collected Al. In these calculations, Al in composite materials is included as part of the Al mass balance, although it is usually not allocated to Al but composite materials. Thus, 1,700 tons of Al foil used in composite packaging material (1,300 tons Al foil in composite material and 400 tons in beverage cartons) were added. The estimated market volume of all Al packaging & non-packaging of 27,700 tons are mostly of rigid material (74%) as Table 3 shows.

Table 3. Market volume and waste generation of Al packaging & non-packaging in tons (values rounded), Austria 2013

Rigid	20,400
Semi-rigid	1,100
Flexible	6,200
Market volume / Waste generation Al	27,700

Al in RW is not only packaging but also of non-packaging. The generated waste contained 5,500 tons of Al non-packaging, about which 1,700 tons were household foil (Amt der Kärntner Landesregierung (Ed.), 2012; ARGE Abfallanalyse Oberösterreich 2013, 2014; ARGE TBH et al., 2016; Boku, 2011; IUT & SDAG, 2014; Land Salzburg, 2013; Salzmann Ingenieurbüro, 2000; TB Hauer et al., 2015).

7,700 tons (82%) of the separately collected Al packaging & non-packaging were of rigid material, while around 700 tons (4%), resp. 4,700 tons (26%) were of semi-rigid, resp. flexible material . The residual waste was thermally (73%) or mechanically (27%) processed.

Around 13,300 tons of Al were fed into waste incinerators, whereof about 1% of Al was removed with the fly ash, while the solid combustion residues (bottom ashes) were further treated. From the bottom ash, 3,000 tons or 22% of the Al fed into incineration plants were recovered.

According to informations given by the operators of MBT/MT plants, which covered 82% of the total treated waste by MBT/MT plants (440,000 tons) in Austria (BMLFUW, 2017), 1,000 tons of Al or 14% of the mechanically treated Al (5,000 tons) were recovered.

While generally the separately collected packaging returns into circulation, from beverage cartons only the paperboard gets recycled. The residual material goes into the cement industry and is no longer part of a circulatory system.

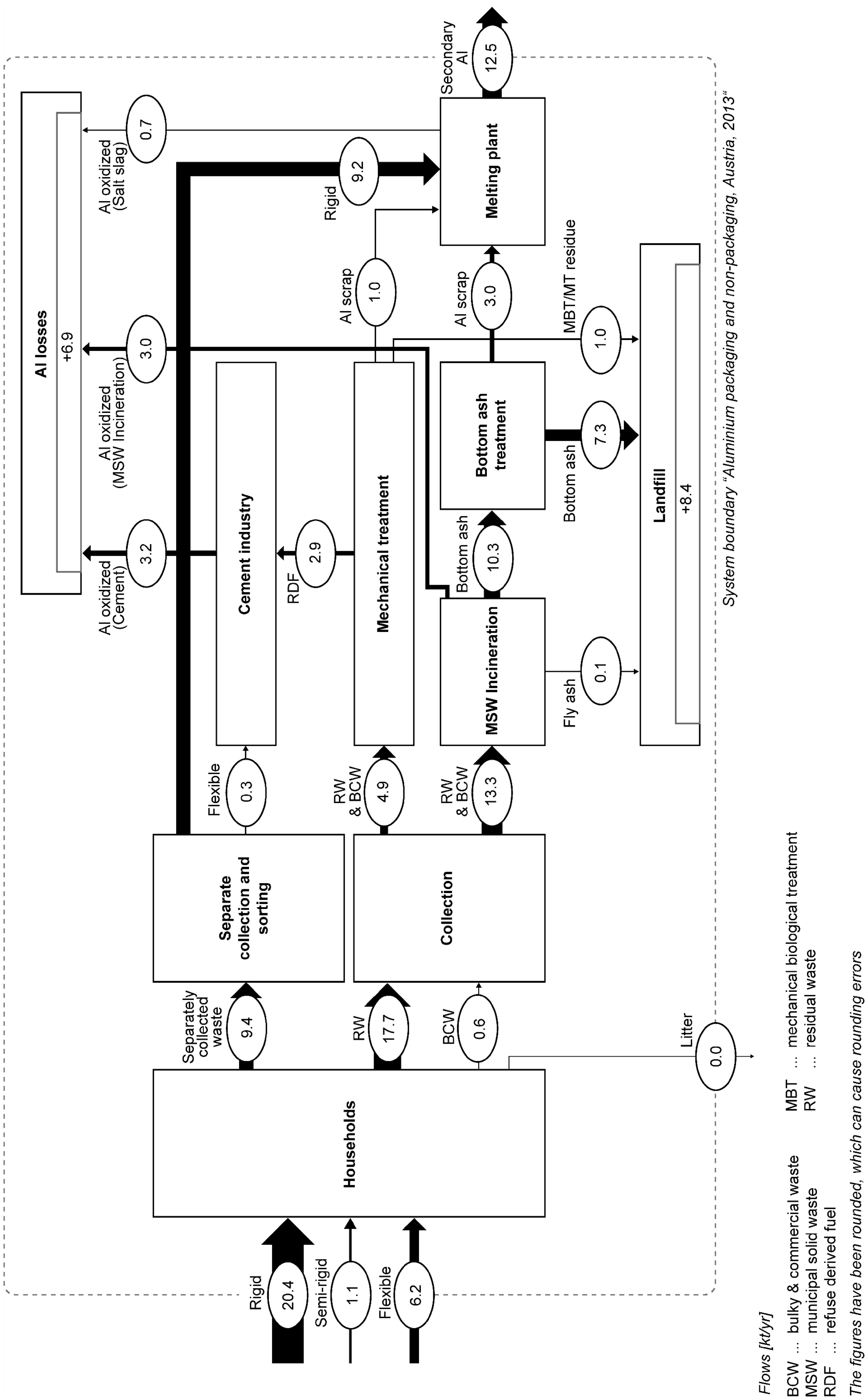


Figure 2. MFA Al packaging & non-packaging (Austria, 2013).

The not recovered Al was lost due to oxidation processes during combustion and insufficient recovery of Al from waste incineration bottom ash and MSW treated in MBT/MT plants. Al melts at around 660°C and forms through the reaction with oxygen Al oxide (Al2O3). The oxide layer protects Al from further oxidation, but strong thermal shock (Biganzoli, 2013) or frictions and collisions with other particles can break the oxide layer and lead to further oxidation (Deike et al., 2014). The oxidation rates for various material strength (58.8% for flexible, 17.4% for semi-rigid and 9.2% rigid Al packaging & non-packaging) were taken from the tests performed by Biganzoli et al. (2012).

Around 3,000 tons of Al is lost through oxidation and 11,300 tons through insufficient recovery. The latter include the losses from MBT/MT residuals going into the cement industry as refuse derived fuel (RDF, 3,200 tons). The collected and recovered Al undergoes a melting process and can be recycled as secondary Al. Oxidation losses during the smelting process and weight deduction of the fed Al caused by adhesions add up to 700 tons. Overall, about 12,500 tons per year of the Al present in packaging & non-packaging household goods are currently recovered and utilized as secondary Al.

4. CONCLUSIONS

Around 27,700 tons of packaging & non-packaging household goods have been used in Austria in 2013. As this work showed, 45% of the Al returns as secondary Al into circulation (see Figure 3), whereby separately collected beverage cans contribute the most. The main losses of Al occur through oxidation (11%) during incineration and limited recovery from subsequent processes or other sorting constrains (42%). The Al present in small grained particles or composite foils in the bottom ash is difficult or impossible to recover, but also insufficient non-ferrous metal separation technologies currently applied at Austrian bottom ash treatment plants, are responsible for these losses.

Regarding the status quo in Austria ameliorating the return rates and expanding the collection schemes might increase the recycling rate of Al packaging & non-packaging. Nevertheless, investments into better separation technologies (non-ferrous metal separation from bottom ash) appear indispensable for a significant increase of the recycling rate of Al and avoiding potential material downcycling.

The return rate of Al packaging is significant higher than the one of non-packaging (40%), displaying the success of the extend producer responsibility scheme in place. This could suggest that at least packaging similar non-packaging products, like household foil or coffee capsule and pads, should be included in obligation schemes.

The results demonstrate clearly that the Austrian packaging industry, collection and recovery systems and waste management need to augment their efforts on a way to a Circular Economy to reach the ambitious objectives for reuse and recycling regarding Al contained in packaging waste of 75% for 2025, resp. 85% for 2030. At present, it is even doubtful if these recycling targets might be reasonable (from an economic and ecological point of view) considering the current portfolio and design of Al packaging.

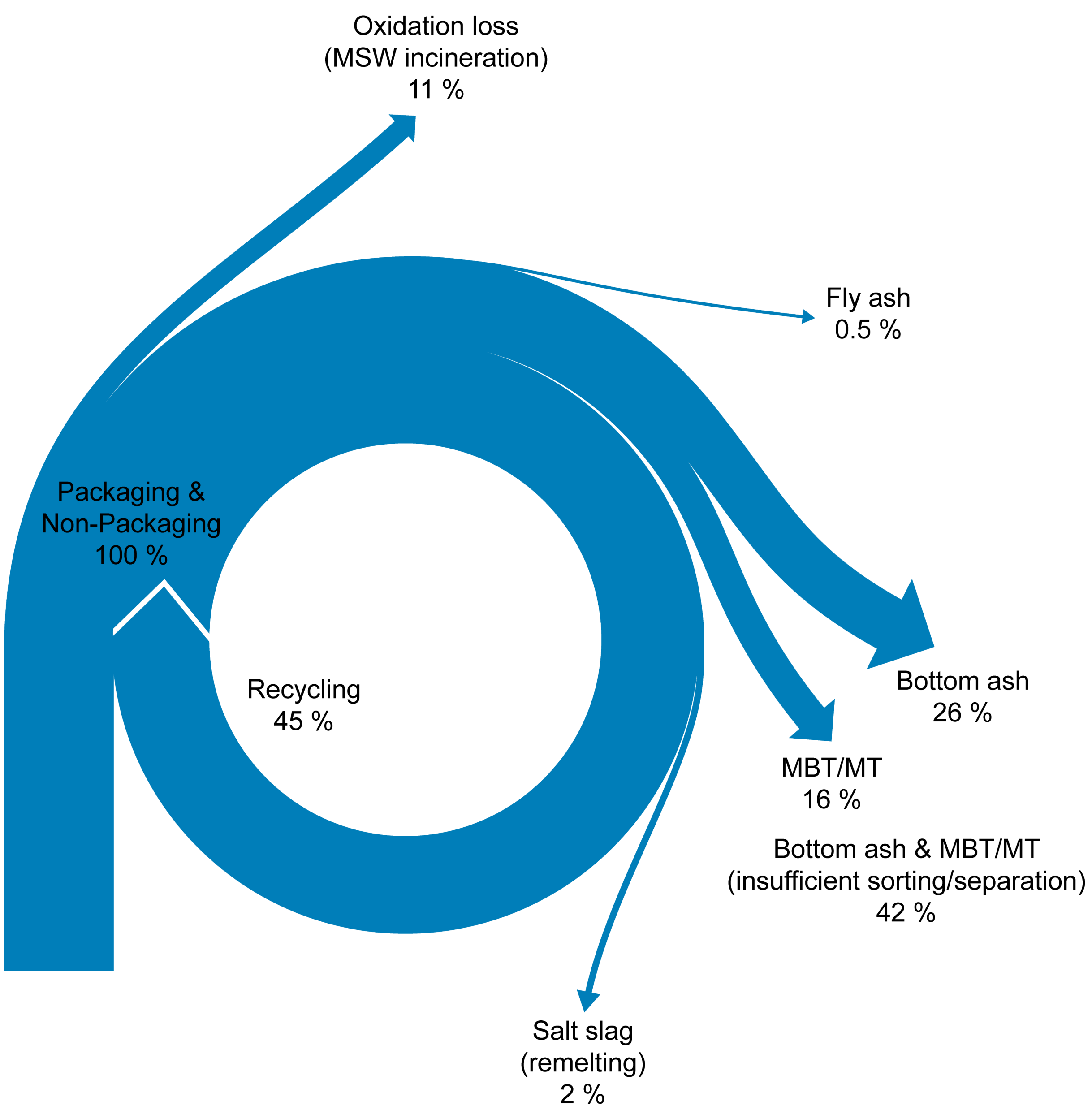


Figure 3. Circulatory system of Al packaging & non-packaging, Austria 2013

ACKNOWLEDGEMENTS

The presented work is part of a large-scale research initiative on anthropogenic resources (Christian Doppler Laboratory for Anthropogenic Resources). The financial support of this research initiative by the Federal Ministry of Science, Researchand Economy and the National Foundation for Research, Technology and Development is gratefully acknowledged. Industry partners co-financing the research center on anthropogenic resources are Altstoff Recycling Austria AG (ARA), Borealis group, voestalpine AG, Wien Energie GmbH, Wiener Kommunal-Umweltschutzprojektgesellschaft GmbH and Wiener Linien GmbH & Co KG.

REFERENCES

Aludium. (2017). Lebensmittelverpackungen. Retrieved from http://aludium.com/de/maerkte/lebensmittelverpackungen/

Amt der Kärntner Landesregierung (Ed.). (2012). Abfallwirtschaftskonzept des Landes Kärnten. 3. Fortschreibung 2012. In Dipl.-Ing. Michael Rabitsch (Ed.). Klagenfurt: Amt der Kärntner Landesregierung. Abteilung 8 (Kompetenzzentrum Umwelt, Wasserwirtschaft und Naturschutz).

ARA. (2017). Getränkeverpackungen *Email: 2017-01-25*.

ARGE Abfallanalyse Oberösterreich 2013. (2014). Restabfallanalyse Oberösterreich 2013. In FHA – Gesellschaft für chemisch-technische Analytik GmbH (FHA GmbH), pulswerk GmbH, & Technisches Büro HAUER Umweltwirtschaft GmbH (TB Hauer) (Eds.), (pp. 143). Wien, Korneuburg.

ARGE TBH, FHA, & pulswerk. (2016). Wiener Altstoff- und Restmüllanalysen 2015/16. Endbericht vom April 2016. In Technisches Büro HAUER Umweltwirtschaft GmbH, Pulswerk GmbH – Beratungsunternehmen des Österreichischen Ökologie-Instituts, & FHA - Gesellschaft für chemisch-technische Analytik GmbH (Eds.). Korneuburg: Im Auftrag der Stadt Wien Magistratsabteilung 48.

Biganzoli, L. (2013). *Aluminium recovery from MSWI bottom ash.* (PhD Doctoral Dissertation), Politecnico di Milano, Milano.

Biganzoli, L., Gorla, L., Nessi, S., & Grosso, M. (2012). Volatilisation and oxidation of aluminium scraps fed into incineration furnaces. *Waste Management, 32*(12), 2266-2272.

BMLFUW. (2014). Die Bestandsaufnahme der Abfallwirtschaft in Österreich. Statusbericht 2013.

BMLFUW. (2015). Die Bestandsaufnahme der Abfallwirtschaft in Österreich. Statusbericht 2015.

BMLFUW. (2017). Bundesabfallwirtschaftsplan 2017 (Entwurf). Teil 1. Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Boku. (2011). Niederösterreichische Restmüllanalyse und Detailanalyse der Feinfraktion 2010-2011. In Amt der NÖ-Landesregierung, Gruppe Raumordnung Umwelt und Verkehr, Abt. Umwelt – und Energierecht (RU3), & Sachgebiet: Abfallwirtschaft und Ressourcenschonung (Eds.): Universität für Bodenkultur. Department für Wasser – Atmosphäre – Umwelt. Institut für Abfallwirtschaft.

Brunner, P. H., & Rechberger, H. (2017). Handbook of material flow analysis For Environement, Resource and Waste Engineers. Second Edition. Bota Raton: Taylor & Francis, CRC Press.

Bühler. (2017). Flexible Verpackungen. Retrieved from http://www.buhlergroup.com/global/de/prozesstechnologien/technologien-fuer-hochvakuum-duennschichtanwendungen/flexible-verpackungen.htm#.WKQnvn9I6UI

Deike, R., Ebert, D., Schubert, D., Ulum, R. M., Warnecke, D. R., & Vogel, M. (2014). Das Recycling von Metallen aus MV-Schlacke. *Müll und Abfall, 1*(14).

EAA. (2016). Aluminium packaging: Convenient, safe and infinitely recyclable.

EAA. (2017). Aluminium packaging: convenient, safe and infinitely recyclsble. *Packaging brochure.* Retrieved from http://www.european-aluminium.eu/media/1346/packaging-brochure_en.pdf

EAFA. (2017). Alu foil in use. Europe 2016. Email 2017-05-29.

EC. (2015). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 94/62/EC on packaging and packaging waste. In EUROPEAN COMMISSION (Ed.), *2015/0276 (COD)* (Vol. COM(2015) 596 final). Brussels.

FKN. (2017). Verbunde sind Hightech-Werkstoffe. Retrieved from http://www.getraenkekarton.de/getraenkekarton/herstellung/verbunde-sind-high-tech-werkstoffe

Fragner, W. (2017). Einschmelzung Secondär-Aluminium *Email: 2017-04-12*.

Hu, Y., Bakker, M., & De Heij, P. (2011). Recovery and distribution of incinerated aluminum packaging waste. *Waste Management, 31*(12), 2422-2430.

IUT, & SDAG. (2014). Sortieranalysen für Restmüll aus der Steiermark. Endbericht. In Ingenieurgemeinschaft Innovative Umwelttechnik GmbH & Saubermacher Dienstleistungs AG

(Eds.): Amt der Steiermärkischen Landesregierung. A14 Referat Abfallwirtschaft und Nachhaltigkeit.
Lamberti, M., & Escher, F. (2007). Aluminium Foil as a Food Packaging Material in Comparison with Other Materials. *Food Reviews International, 23*, 407-433.
Land Salzburg. (2013). Restmüllanalyse 2012 *Email: 2016-12-19*.
Laner, D., Feketitsch, J., Rechberger, H., & Fellner, J. (2016). A Novel Approach to Characterize Data Uncertainty in Material Flow Analysis and its Application to Plastics Flows in Austria. *Journal of Industrial Ecology, 20*(5), 14.
Loimayr, B. (2010). Littering. Das achtlose Wegwerfen von Müll in die Umwelt (pp. 33): Land Steiermark. Fachabteilung 19 D, Abfall- und Stoffflusswirtschaft.
López, F. A., Román, C. P., García-Díaz, I., & Alguacil, F. J. (2015). Oxidation and waste-to-energy output of aluminium waste packaging during incineration: A laboratory study. *Waste Management, 43*, 162-167.
OECD. (2015). Material Resources, Productivity and the Environment. In OECD Publishing (Ed.), *OECD Green Growth Studies,* . Paris.
PROPAK. (2017). PROPAK Verpackungssektor. Das Meistverwendete unter den Materialien. Retrieved from http://www.propak.at/verpackung/propak-verpackungssektor
Republik Österreich. (2014). Verpackungsverordnung 2014 (Vol. BGBL II Nr. 1842014,). Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.
RLI. (2015). Circular economy: From wish to practice. Advisory report. In The Council for the Environment and Infrastructure (Ed.). Den Haag.
Rüttinger, L., Treimer, R., Tiess, G., & Griestop, L. (2016). Fallstudien zu Umwelt- und Sozialauswirkungen der Bauxitgewinnung und Aluminiumherstellung in Pará, Brasilien. Berlin: adelphi.
Salzmann Ingenieurbüro. (2000). Restmüllanalysen 2000. Amt der Vorarlberger Landesregierung (pp. 42).
Sörme, L., & Hedbrant, J. (2001). Data vagueness and uncertainties in urban heavy-metal datacollection. *Water Air Soil Pollution, 1*(3-4), 43–53.
Stadt Wien MA 48. (2017). Metallrückgewinnung *Email: 2017-03-03*.
Taverna, R., Frühwirth, W., & Skutan, S. (2010). Produktbezogene Stoffflussanalyse von Abfällen in der Wiener Restmüllanalyse. Wien: Technische Univeristät Wien. Institut für Wassergüte, Ressourcenmanagement und Abfallwirtschaft. Abteilung Abfallwirtschaft und Ressourcenmanagement, GEO Partner AG, Denkstatt GmbH,.
TB Hauer, A.C. Nielsen, & ÖIV. (2015). Verpackungsaufkommen in Österreich 2013. Endbericht 29.6.2015. Korneuburg.
TBU. (2010). Restmüllanalysen Tirol 2010 In Amt der Tiroler Landesregierung (Ed.), (pp. 47). Korneuburg: Technisches Büro für Umweltschutz GmbH.
Verbund AG. (2017). Die Donau. Retrieved from https://www.verbund.com/de-at/ueber-verbund/kraftwerke/gewaesser/donau
Weidema, B. P., & Wesnæs, M. S. (1996). Data quality management for life cycle inventories-anexample of using data quality indicators. *Journal of Cleaner Production, 4*(3), 167-174.
Wien Energie. (2012). Flugaschen aluminium-Gehalt *persönliche Mitteilung*.
Wilts, C. H. (2016). Germany on the road to a circular economy? In Friedrich-Ebert-Stiftung (Ed.), *WISO DISKURS 10/2016*. Bonn.