Feasibility of aluminium component dismantling from ELV

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Writer

Company: IRT M2P	**First Name NAME: Gaël FICK**
Tel. :	**Email : gael.fick@irt-m2p.fr**

Project manager

Company: IRT M2P	**First Name NAME: Gaël FICK**
Tel. :	**Email : gael.fick@irt-m2p.fr**

Abstract

Key words: aluminium recycling, end-of-life vehicle, dismantling, aluminium refining, remelting, circular economy

The current recycling process for End-of-Life Vehicles (ELV) – shredding and post-shredder sorting – results in the production of aluminium scraps containing a mix of alloys (cast and wrought), and sometimes small amounts of other undesirable materials. Today, this scrap quality fits the requirements of European refiners for recycling into cast alloy ingots, which can be remelted to produce parts for the automotive industry. However, the increasing share of wrought alloys in cars will increase the loss of these alloys if recycling practices remain unchanged. Indeed, as most wrought alloys are produced from primary aluminium and usually contain lower alloying elements than cast alloys, achieving closed-loop recycling, alloy-to-alloy or wrought-to-wrought and cast-to-cast, could help reducing the need for primary metal and, in a lesser extent, of alloying elements. From this perspective, the main flaw in current recycling processes is the practice of shredding the car as a whole which results in a mix of alloys: dismantling aluminium components before the shredder could be a solution.

This work investigated the economic and technical feasibility of such a dismantling process in order to provide recommendations to European Aluminium.

The work involved three main activities:

- Interviews with actors of the recycling chain for ELV-related aluminium: dismantlers, shredders, recyclers (remelters and refiners) and recycling related associations.
- Modelling of aluminium flows from ELV from 2020 to 2040.
- Economic assessment of the dismantling of a shortlist of aluminium components.

The results show that improving the dismantling of aluminium components at the Authorised Treatment Facility (ATF) level is neither a technical nor a technological problem as tools exist for manual dismantling or with destructive tools. However, there are profitability and logistic issues. Dismantlers also indicate the need for additional and detailed technical information and data, from OEMs as well as aluminium producers. This data will help better identify components with the highest recycling value, improve the dismantling and sorting efficiency and more generally determine whether this activity is profitable or not. At shredder level, little can be changed for the moment as most shredders have no issues selling their current scrap qualities (within and outside of Europe). Finally, for refiners and remelters, accessing cleaner scrap from ELV would be welcome.

The mass flow evaluation showed that, in Europe, there is an overall potential for an increase in "clean" aluminium scrap (wrought separated from cast) via increased dismantling practices. This could be further improved by an increase in the collection rate of ELV in Europe and, if possible, reduced export of second-hand premium vehicles with high aluminium content. On a more local-scale, the low volumes expected to arise from ELV dismantling at individual ATFs make the evolution of practices difficult. A solution could be for various ATFs to work together with shredders and/or within a network to create a critical mass or centralise material flow before dealing with the aluminium producers.

The economic assessment performed for a shortlist of 7 components, shows that dismantling costs would mainly be driven by time/labour costs as well as investment). It is profitable only for heavy components (more than 10 kg)

and less than a few minutes of dismantling time. These heavy components include battery cases for electric or hybrid vehicles as well as heat exchangers. For other components, dismantling time must be further optimized or scrap prices significantly higher to ensure a sustainable business model for dismantlers.
Finally, some recommendations are listed to help improve dismantling practices and automotive component design with respect to recycling.

Versions

Version	Date	Comments
1	09/02/2021	First draft
2	25/02/2021	Modifications from European Aluminium
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Recipient(s)

First Name NAME	Company
Patrik RAGNARSSON	European Aluminium
Benedetta NUCCI	European Aluminium

Comments

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Background

Aluminium demand in the transport sector in 2019 exceeded 5 000 000 t per year and is expected to increase by 55% by 2050 (European Aluminium 2020). Focusing on the automotive industry, before the economic recession associated with the Covid-19 pandemic, new registration trends in Europe were foreseen to increase in the next 5 to 10 years. In addition, aluminium content in vehicles has been steadily increasing over the past 40 years mostly due to light-weighting efforts and the substitution of steel by aluminium. Aluminium alloys currently used in the automotive industry are mainly cast: for mechanical parts, casings and wheel rims. However, there is a growing tendency to use wrought alloys for closures, body in white and electric vehicle-related components. Overall, aluminium demand for the automotive industry will keep increasing as will concerns with its environmental impact. On average, primary aluminium production emits 6,7 tonne of CO_2-eq per melted tonne in Europe, whereas imported aluminium can reach 10.6 tonne of CO_2-eq per tonne (European Aluminium 2020). Amongst possible mitigation solutions, the European Aluminium circular action plan for 2050 suggests the improvement of end-of-life recycling practices for closed loop recycling, in order to reduce the need for primary aluminium imports.

The current recycling process for End-of-Life Vehicles (ELV) – shredding and post-shredder sorting – results in the production of aluminium scraps containing a mix of alloys (cast and wrought), and sometimes small amounts of other undesirable materials. Today, this scrap quality fits the requirements of European refiners for recycling into cast alloy ingots, which can be remelted to produce parts for the automotive industry. However, the increasing share of wrought alloys in cars will increase the loss of these alloys if recycling practices remain unchanged. Indeed, as most wrought alloys are produced from primary aluminium and usually contain lower alloying elements than cast alloys, achieving closed-loop recycling, alloy-to-alloy or wrought-to-wrought and cast-to-cast, could help reducing the need for primary metal and, in a lesser extent, of alloying elements. From this perspective, the main flaw in current recycling processes is the practice of shredding the car as a whole which results in a mix of alloys: dismantling aluminium components before the shredder could be a solution.

Since the European directive 2000/53/CE on End-of-Life Vehicles (ELV) was adopted by the European commission in 2000, and its implementation in 2002, European members states have transposed the directive into laws to organize the collection and treatment of ELVs withing their borders. In 2017, 5 292 000 ELVs were reported and collected in Europe, which represents 5 700 000 tonnes (Eurostat 2017). More than 60% of these ELV were recovered in 3 countries: France, Italy and UK (respectively 1.1, 0.9 and 1.3 million ELVs). The average age of ELV in Europe lies around 14 years old (Öko-Institut e.V. 2017) but it varies significantly over Europe and it has been increasing in the past 10 years.

Table 1: Statistics on new vehicles and ELV in 2017

Country	New registrations	Number of collected ELV	Average age [years]
France	2 110 748	1 138 742	18,5
Italy	1 971 345	990 876	15,6
UK	2 540 617	1 390 185	14,2
Europe	14 318 493	5 292 000	14

As can be seen in Table 1, there is a significant gap between the numbers of new registrations each year and the number of ELV collected. It can be explained by three different factors: the average scrappage rate (average age of ELV) ; the export of vehicles to East European or non-European countries for parts or repair and second life ; the unauthorized treatment or illegal export (Öko-Institut e.V. 2017).

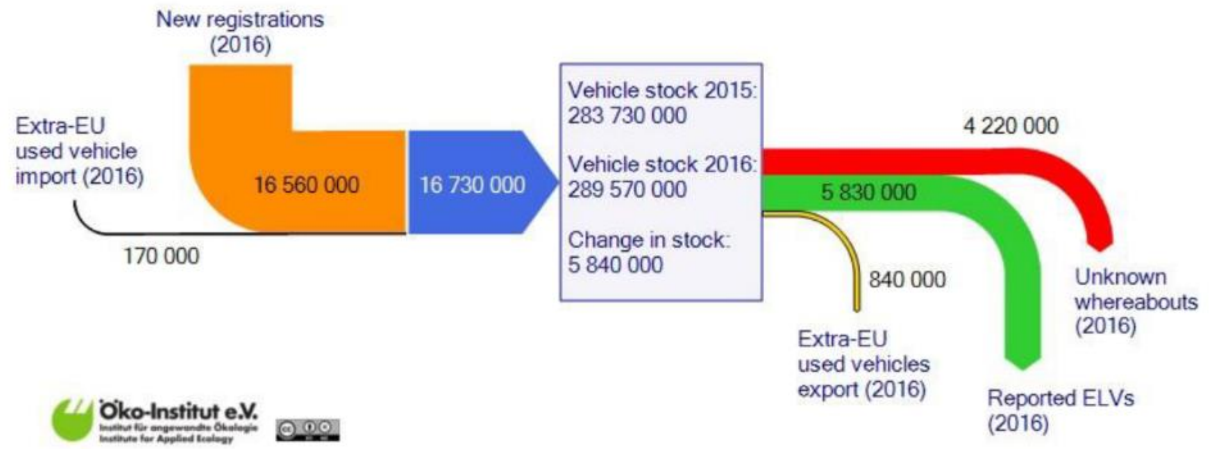

Figure 1: Vehicle entries and exits of the EU 27-fleet for 2016 (European Commission 2020)

On average, ELVs contain around 75% of metals, from which about 5% are non-ferrous. Although aluminium content of new vehicles has been very well documented in the different Ducker studies (2012, 2016; 2019), few data is available on the actual aluminium content in collected ELV. Rough estimation based on aluminium content of 15-year-old cars (around 105 kg of aluminium) would show that around 550 000 t of aluminium are expected to reach end-of-life per year within Europe. However, the actual aluminium content for ELVs collected nowadays in European countries is much lower because the average age of ELV is close to 20 years old in some countries, and almost all premium vehicles, with high aluminium content, are not treated in Europe (export for reparation and second life).

Aluminium content in European vehicles has been increasing since 2000, and is expected to keep increasing – from 179.2 to 198.8 kg of aluminium per car on average between 2019 and 2025 according to Ducker (2019) – the volumes of aluminium extracted from the treatment of ELV should increase in the next 20 years. To assess the mass flows of the different aluminium alloys actually arising from ELV today and those expected in the next 20 years, it is necessary to take into account several important parameters:

- evolution of aluminium content in vehicles over the last 25 years,
- aluminium content associated to each segment market,
- evolution of new registrations in Europe (from 1990 to 2035),
- evolution of the share of vehicles over the different segment markets,
- average age of ELV in Europe,
- ELV collection rates for each segment market,
- dismantling rates for aluminium components.

A mathematical model, based on dynamic Material Flow Analysis (dMFA) methodology, has been used to assess these figures for Europe, first globally (all aluminium content in cars), and then specific calculations were made for a list of 20 components[1] selected by European Aluminium members. To

[1] Shortlisted components: A-pillar, Battery trays, B-pillar, Clutch housing, Cylinder heads, Electric motor housing, Engine block, Fender/Wing, Front bumper, Front door, Gearbox casing, Heat exchangers, Heat shield, Hood, License plate, Mounts, Oil pans, Pistons, Rear bumper, Rear door, Rims, Shock towers, Tailgate

take into consideration the potential evolutions of ELV collection and dismantling practices, four scenarios were considered:

- ideal case, for which all ELV are considered collected by ATF (no legal nor illegal export, no stock increase, no illegal scrappage), and all shortlisted components are dismantled before shredding the carcasses,
- current case, using today's practices,
- optimistic case, considering an improvement of the collection and dismantling practices,
- pessimistic case, considering a degradation of the collection and dismantling practices.

Table 2: Expected mass flows of aluminium arising from aluminium components in ELV, all aluminium components considered (figures for Europe in 1000 tonnes)

		Ideal case	Current	Optimistic	Pessimistic
2020	Collected at EoL	1 779	603	1 226	475
	Stock increase / Exported / Unknown	-	1 174	552	1 302
2030	Collected at EoL	2 103	647	1 432	504
	Stock increase / Exported / Unknown	-	1 546	671	1 599
2040	Collected at EoL	2954	818	1 993	630
	Stock increase / Exported / Unknown	-	2 136	961	2 325

Should the practices remain the same as today's, around 22% of aluminium in shortlisted components would be recovered through dismantling, 11% as shredder residues and the rest (67%) would not be available for recycling. The majority of aluminium alloys recovered (dismantled and/or shredded) from ELV would be cast alloys (around 80% today, and 70% in 2040) in the rims and engine components. Concerning wrought alloys (1xxx-series through 7xxx-series), about 10% would be dismantled and 20 % would end up in shredded residues, the 70% remaining (around 50 000 t in 2020) would be in the EVL exported or of unknown whereabouts.

Improvement of practices, and especially collection rates, could help increase the amount of aluminium recovered through dismantling by 150 % (reaching 55% of the overall aluminium), and more specifically reach around 45 % of wrought alloys collection and dismantling.

Dismantling aluminium components from ELV before shredding would have many economic and environmental interests:

- Reduce the need for of additional alloying elements (0,5 to 5% of raw material input), new scrap (pre-consumer scrap) or primary aluminium, and thus increase overall sustainability,
- Minimize the recycling effort ahead of the furnace and thus reduce the costs of the overall process,
- Increased closed-loop recycling, using sorted fractions back into their initial applications (sheet, extrusion, cast).

Current recycling practices

The overall process of ELV treatment and aluminium recycling is quite similar in all European countries. The implementation of the ELV directive drove the uniformization of the beginning of the ELV recycling process (depollution). The rest of the process has harmonized itself over European recycling companies which tried to stay at the same level as their competitors.

The treatment process, from ELV end-user to new aluminium ingots or products includes 3 to 4 major steps (transportation steps excluded): ELV treatment at ATF level, shredding and post-shredding residues sorting, aluminium residues refining, and, finally, scrap remelting at refiners or remelters.

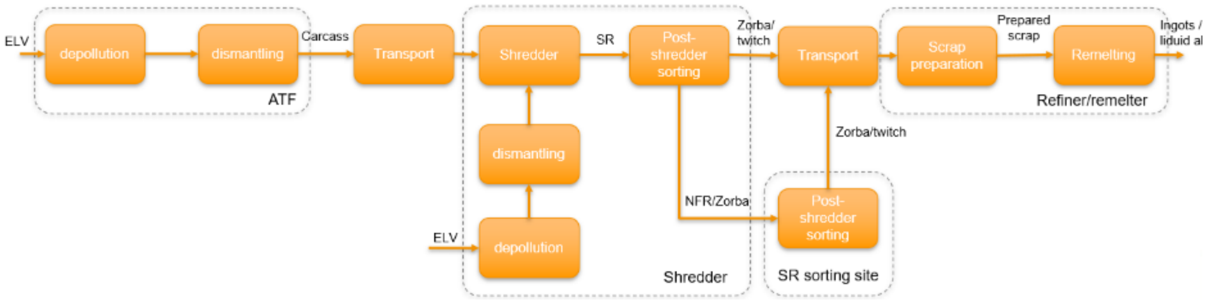

Figure 2: Overall ELV treatment process in Europe (SR: Shredder residues, NFR: Non-ferrous Residues)

Practices at ELV treatment at ATF level

Since the implementation of the ELV Directive, each EU member gets to authorize the facilities, called Authorized Treatment Facilities (ATF), which can treat the ELV and emit the certificate of destruction. There are approximately 12 900 ATF in Europe, 1650 in France, 1700 in Italy and around 1800 in UK (ARGUS 2016; ADEME 2018). ATFs can have very diverse structure types and sizes: between 1 and more than 20 employees, treating between 100 to more than 5000 ELV per year (ADEME 2015).

There are three main types of ATF:

- Dismantlers for parts who pick specific list of parts for re-sale,
- Dismantlers for scrap (small scale ATFs) who dismantle for scrap value only, removing specific parts and splitting different metals for varied sale (copper, aluminium, steel etc.) and send the hulk for processing,
- Scrap metal dealers and shredder who depollute and then directly shred the ELV.

ELV treatment process at ATF involves 5 main steps :

- ELV Collection: ATF can collect ELV from private individuals, garages and car dealerships, pounds and insurances. Due to the value of metals, in most European countries ELVs have a positive market value, ATFs need to buy the ELV. On average ELVs in France cost 140,2 € in 2013 (ADEME 2015), but the actual cost can vary significantly depending on the sources (private holder or insurance), between 50€ and more than 1000 €/ELV for premium vehicle.
- ELV assessment: each ELV pass through an expertise area where components suitable for re-sale or recycling are listed and their quality checked.
- Depollution: regulated process and must be performed according to the ELV directive. At this step all hazardous substances and parts have to be removed (fuel, battery, catalytic converter, wheels, tires…). Overall, the depollution process represents a cost for the ATF as it requires investments, human resources and the collected substances must be disposed of.
- Dismantling for re-use: components identified during the ELV assessment then are manually removed by qualified operators.
- Dismantling for recycling: this can be done either cleanly by hand, using the dismantling line and associated equipment or destructively using power tools to tear apart the components from the ELV.

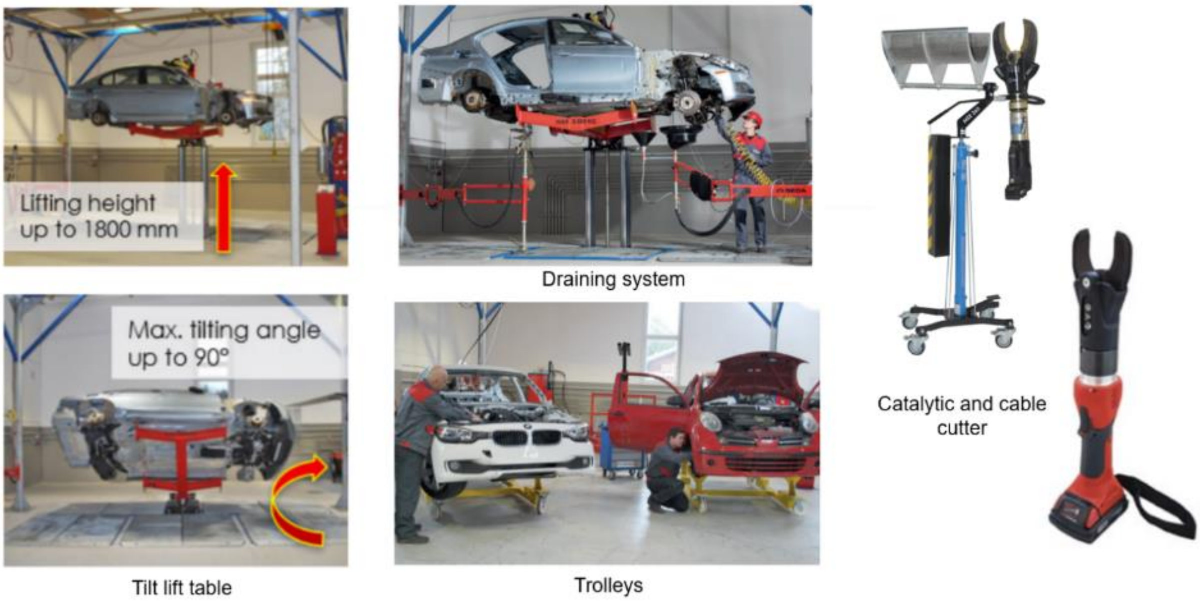

Figure 3 : Examples of standard pieces of equipment for depollution step (SEDA)

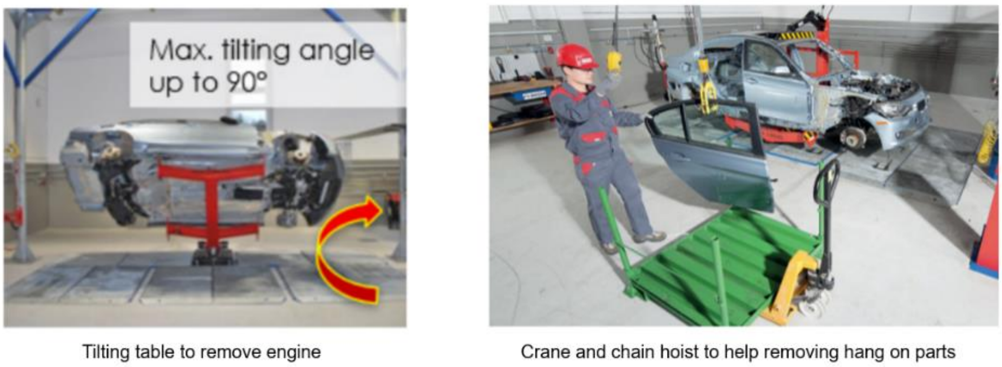

Figure 4 : Examples of standard equipment for hand dismantling, for recycling (SEDA)

Figure 5: Examples of destructive dismantling devices which can be used at ATF or shredder level

Practices at shredders and scrap dealers

The business of most shredders and scrap dealers is very different from the ATFs. They process large volumes of scraps, mainly metals (and most of all ferrous scrap). ELV for a shredder is a feedstock, which need to be treated as quickly as possible to obtain the main output: ferrous scrap. Most shredders only perform the shredding and a part of the processing of the post-shredding residues to sort an enriched fraction of aluminium scrap. On these shredding sites, no dismantling is performed.

European shredding capacities are much larger than the volumes of vehicles reaching end-of-life each year. Usually, shredding facilities process a mix of ELV and other end-of-life products (construction wastes, household appliances carcasses...). In France, about 30 to 40 % of input feeds are ELVs (for interviewed shredders), 85% in Italy, 20-25% in Sweden.

The overall process from the ELV carcass to aluminium scrap fractions used by the refiners/remelters is approximately the same in every European country (Figure 6).

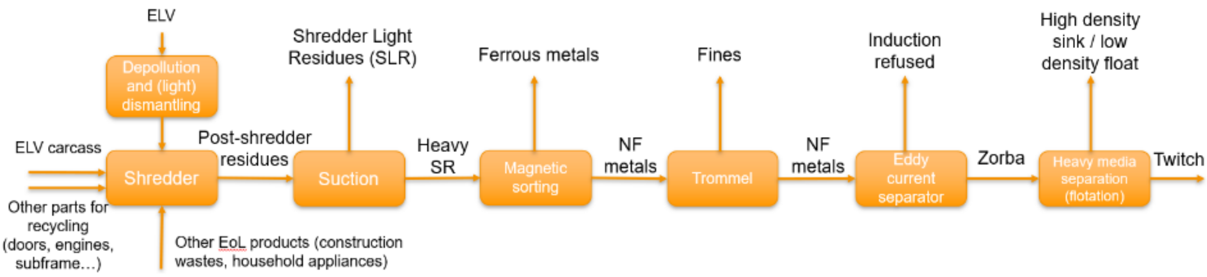

Figure 6: ELV treatment process at shredder level

First of all, the ELV hulk is shredded using shredders called “hammer mills”. The shredder is usually equipped with an aspiration mechanism which sucks the fines and light residues from the shredder drum. Grills on the output of the shredder allow sufficiently shredded pieces of residues to escape the shredding chamber and end up on a conveyor belt. These residues are called heavy shredder residues (HSR). They first pass through a magnetic sorting process (can be a magnetic overband) to remove the ferrous and magnetic fraction from the HSR and produce a Non-Ferrous fraction (containing approximately ~20% of aluminium). Most plastics are removed from these residues using an eddy current sorting machine, to obtain a residue called Zorba, enriched in aluminium (~50-60%). Zorba can then be treated to obtain a more aluminium-rich scrap fraction, either directly on the shredding site or on mutualized centres, using a process called flotation (heavy media separation or sink-float separator) or an X-ray transmission process. The aluminium output of this process is called twitch (Aluminium content must be greater than 95% to be considered as Twitch according to ISRI classification (ISRI 2020)).

The processing of post-shredding residues to increase their aluminium content is also expensive. The following devices can be used:

- Eddy current separator to separate metallic elements (Zorba) from organics,
- Flotation (heavy media separation / sink-float separator) enabling the refining of Zorba by removing higher density elements (other metals) and lower density (plastics) and obtain Twitch,
- X-ray transmission separation to refine Zorba into Twitch.

Logistics

Logistics is an important issue in scrap recycling as it can increase significantly the cost of the scrap depending on the type of scrap, its bulk density and transport distances.

Aluminium from ELV needs at least 4 major transport steps:

- ELV collection by ATF: the distances range from a few kilometres to several dozens.

- Once ELVs are processed by the ATF, the carcasses have to be transported to shredder plants. In Europe, the distance between dismantlers to shredders lies between 10 and 50 km, but shredders can increase their supply distances to more than 150 km.
- Aluminium scrap (Zorba or Twitch) is usually transported by 80 m^3 truck, compacted (around 20 t per truck) and supply distances vary a lot: between 100 km from local scrap dealers and dismantlers to more than 500 km from foreign scrap dealers (on average around 300 km by truck).

In a new recycling scheme with higher dismantling rates of aluminium components for recycling, a fourth transport step would likely be required: transport of aluminium components ATF and shredders or aluminium producers. Indeed, for most components, aluminium volumes available today and in the next decade are still quite low and individual ATF might not gather enough ELV, and thus ELV components, to be able to sell and ship to aluminium producers. There will then probably be a need for global strategies between ATF, ATF networks for example, or other geographical regions to set a mutualizing scheme into place.

Setting this type of strategy is up to the ATF and ATF networks as many parameters need to be taken into consideration. ATF will need many information and global data to assess the relevance of dismantling and mutualisation strategies.

Practices at aluminium refiners and remelters

Overall, refiners and remelters contacted in the frame of the study produce approx. 1 500 kt/year[2]. It represents a scrap consumption of approx. 1 300 t/year[3], from which around 450 kt/year come from ELV components or from shredded residues containing ELV residues. Most of the refiners and remelters use wheel rims and post-shredder mix residues (respectively 75 and 50% of them). Half of them use engine components, and 25% use no ELV related scrap and only use new scraps (pre-consumer scrap) or end-of-life scrap from other products.

Each delivery of scrap has to consist of specific grades of scrap, usually as classified by ISRI (e.g., cast, wheels, taint tabor). Scrap buyers specify in the orders a set of requirements that each type of scrap must fit amongst the following: chemical composition, metal content, percentage of allowed impurities, size, shape.

The chemical composition is the most important requirement, and it is closely related to the alloys produced by the company. Refiners can accept almost any type of aluminium scrap in terms of composition whereas remelters have more rigorous requirements and need scraps with either very similar composition as their products, or very low alloyed (for example 1xxx series).

For most producers, iron attachments must be avoided, however some of them (mainly refiners) can buy aluminium scrap with iron attachments depending on the price.

All aluminium producers have internal processes to monitor the quality of their incoming scraps before their use in the process. This process uses laboratory or semi-industrial equipment (sample/small rotary furnace, spectrometer, etc.), whose costs are considered either low or negligible compared to the other process costs. When the monitored raw materials (scraps) don't fit the requirements, the delivery is not accepted, or it can be downgraded and have an impact on the price paid to the supplier.

[2] Figure calculated on the basis of the volumes supplied by the companies or from their respective websites when not provided.
[3] Calculated on the basis of global volumes and individual scrap consumption declared by the companies.

All scrap grades used by refiners and remelters cannot be directly remelted, on average around 40%[4] of the scraps need to pass through a preparation process first, which can represent a significant part of the costs for the producers. This process can include crushing or shredding, sieving, sorting (magnetic, eddy current, x-ray, flotation), baling / compacting, drying, rotary furnace, delacquering...

Once the scraps are prepared, they can be melted, but once again, depending on their types and composition, different furnaces can be used: for example, rotary furnace for contaminated scraps (organics, other metals...), chamber furnace for clean scraps without or with low contamination.

The use of rotary furnaces results in the use of salts to collect the impurities (oxides), which, in the end, results in the production of salt slags whose recycling is mandatory in Europe and results in additional costs for the producer.

There can be different furnace types on one production site for flexibility. Production plants with no rotary furnace are then limited in the type of scrap which can be used.

The overall metal recovery[5] (from scrap to ingot) can vary between 60% and 98% depending on many factors such as the type of scrap, its impurity content and physical properties, and the preparation processes used. To reduce losses, it is essential to adapt the furnace to the type of scrap (rotary furnace for contaminated scrap yields lower or equal to 90%, for clean scrap metal yield in chamber furnace reaches around 95%).

Evolution of recycling practices

In order to increase the dismantling rate of aluminium components for recycling, changes would have to be set in place to help at each recycling step (ATF, shredders, refiners and remelters). Dismantlers/ATFs would need two main changes: improved dismantling databases (such as IDIS – International Dismantling Information System) and enhance training. Improved dismantling databases, with more precise data on parts (material types, dismantling process...) could help ATF owners understand the financial benefits of spending more time for dismantling, alloy-to-alloy sorting and/or cast-wrought separation, or benefit from the dismantling of components for depollution or re-use to access other aluminium components of interesting recycling value. Enhance training will help them identify and separate alloy-to-alloy or cast from wrought alloys, using available technics for alloy identification (mobile spectrometer) and performing separated storage.

Dismantling practices at shredder level can only happen for shredders which are also ATF (where full ELVs are treated). They could increase the number of ELV parts removed by destructive means (tools), but like for dismantlers, sufficient knowledge is required (interesting parts, composition…), and access to more precise information from databases. Improved sorting processes (XRT, LIBS…) could also be useful for a few specific components with mixed materials, such as hang-on parts, which will need separated shredding and sorting if removed at dismantling step.

Refiners and remelters would both be willing to access to improved quality scraps, or more scrap from ELV. However, they have specific requirement, which can differ from one producer to another:

- Clean separation between cast and wrought alloys, and for some producers cast/rolled/extruded. Refiners need cast alloys to ensure a sufficient content of copper and silicon (e.g. a minimum of

[4] Depending on the producers, it concerns between 0 and 100% of the scraps. This share is low for remelters, high for refiners.
[5] Metal recovery is different from "metal yield". Metal yield is the metal content of a scrap

50% of cast alloy in shredder residues). For remelters the demand would be for scrap with wrought alloys and possibly no cast alloy elements, to avoid bringing too much Si, Mg or Cu.
- If possible, separation between wrought alloy groups, for example to separate Al-Si from Al-Mg, or separation of extrusions from sheets (if free from other alloys) to allow closed-loop recycling.
- Scrap stemming from dismantled components should be free from unwanted elements (minerals and heavier and lighter metals, especially free iron, free copper).

For all producers, better ELV scrap quality would probably replace currently used scraps, either pre-consumer scrap, other ELV scrap, or primary aluminium, but for the latter, it will be strongly dependent on the actual composition of the scrap produced from dismantled components.

Evolution of recycling technologies

According to dismantlers, with today's technologies, every component can be removed from ELV, either by hand or with specific tools. The skills, tools and infrastructures already exist, it only needs to be economically possible. Currently, dismantling equipment manufacturers do not offer many new technologies, however hand dismantling efficiency and thus perhaps aluminium component sorting, could be improved with the use of mobile spectrometer (which requires additional labour time, investment and storage space), equipment to help reducing operator loads, and specific training to increase efficiency through quicker dismantling (processing with optimized sequence).

At shredder level, main manufacturers of sorting equipment are developing two new technologies: X-RAY sorting and laser sorting technology (LIBS). They both could be used to better separate post-shredding residues (either coming from the shredding of complete ELV or from the shredding of selected components):

- LIBS technology already exists and works but the capacities are not yet sufficient to be used widely and at industrial scale for processing shredder residues. It could however already be used on wheels to perform a separation by alloy (cast versus forged wheels for example). Today's aluminium market and scrap value sales make alloy-to-alloy separation not needed.
- Shredders have also tried X-ray sorting technologies but there's one main limitation: aluminium in ELV is mostly cast alloy (> 70%) and currently there is no reason to improve its quality since the current fraction is already fully recycled.

Moreover, the interviews with the shredders and scrap dealers showed that using new sorting technologies for enhanced scrap quality is not simple and could be expensive: increased cost overall (direct investments as well as administrative, operating and labour costs), monitoring and analysing final scrap quality would be mandatory and would represent additional and significant investments for shredders, more generally, using new sorting technologies would require more storage space as all qualities need to be stored separately (space is always critical at the recycling yard).

Economic assessment

The main driver but also the main issue concerning the dismantling of specific (aluminium) component from ELV is the economic balance: the component selling price must cover all the costs associated with its dismantling, and this selling price must be lower than the scrap price the aluminium producers are prepared to pay for.

This economic assessment is focused on the components with significant volumes potential by 2040 (from European Aluminium members shortlist), which covers components with sheets, extrusions and castings, some of them being single alloy components, others are mix-alloys:

- Front and rear doors
- Hood
- Front and rear bumpers
- Shock towers
- Battery trays
- Heat exchangers

All engine and transmission related components also presented significant volumes, but as they already are very well dismantled for re-use or recycling, it was decided not to include them in this part of the study.

The aluminium scraps recovered from ELV component dismantling would be sold at market price, which depends strongly on the scrap quality. Two major trading places set the prices for aluminium and aluminium scraps: London Metal Exchange (LME) and European Premium Duty-Paid (ECDP) or Metal Bulletin (MB). LME-based trading prices are usually used for high quality aluminium scraps, home scrap or wrought alloy scrap with low contaminant content. These scrap prices are calculated on the basis of LME Aluminium with a discount (a fixed amount or a certain percentage) whose value depends on the amount of work to be done on the scrap (depends on the properties of the scrap: physical form, contaminant content) and on logistics. ECDP-based trading prices are usually more adapted to end of life scraps with high content of contaminants (typically shredder residues, mix castings...). A significant share of aluminium is also bought on the spot at fix prices. Making sound and precise estimations is not possible as LME Aluminium prices varied between 1400 and almost 2600 $/t in the last 4 years (LME 2020).

The minimum dismantling cost for a dismantler or shredder processing an ELV, is the sum of all the costs associated to the dismantling process of one tonne of specific component (without margin). A dismantling unit has to face 5 major costs to run its operation: ELV collection and transport costs ($C_{ELV\ c\&t}$), ELV depollution costs ($C_{ELV\ dep}$), specific investments ($C_{spec\ invest}$), labour costs for dismantling ($C_{lab\ dis}$), carcass depreciation costs ($D_{carcass}$), transportation costs (C_{trans}). Once the ELV carcass is depolluted and all interesting components are dismantled, the carcass is sold to a shredder (if not already on shredded site) which represents an income (P_{scrap}) which will depend on the weight of the carcass and on the current price of ferrous scrap[6]. The formula used for the calculations is given in equation 1.

$$C_{Component} = \left(C_{ELV\ c\ \&\ t} + C_{ELV\ dep} - P_{carcass}\right)\frac{t_{dis\_comp}}{t_{dep}+\sum t_{dis\_comp}} + C_{spec\ invest} + C_{lab\_dis} + D_{carcass} + C_{trans} \qquad 1$$

For each dismantled component different scenarios were built taking into account the dismantling in itself (by hand or using power tools), separation, potential size reduction and sorting process, before shipping them to the aluminium producers.

First calculations were performed on the basis of average values for the parameters with high variability. The cost breakdowns have also been computed for one of each group of scenarios and there are shown on Figure 7. The results show that economic feasibility is difficult to assess for most components because the average values are close to the scrap prices ranges estimated (no or low

[6] In theory, the carcass price should also reflect the composition of the carcass and should depend on its actual metal content, steel, but also copper and aluminium. The lesser copper and aluminium components are left in the carcass, the lesser should the carcass be sold. This is however currently not really taken into account for transactions between ATF and shredders.

margin possible) and the uncertainty associated to these results is significant as many parameters come into play. We can however note a few tendencies:

- Dismantling doors and hoods is costly (estimated between 700 and 2000 €/t) but could be economically viable depending on market conditions. The cost breakdown shows an even distribution between labour costs (36%), depollution (28%) and specific investment (26%).
- Thorough hand dismantling of doors or hoods does not seem economically feasible, mostly due to the high labour costs.
- Bumpers seem to be difficult components to dismantle (not profitable, estimated between 1400 and 2300 €/t), mainly because of their low weight (< 5 kg) compared to the dismantling time and/or investments.
- Heat exchangers could also prove profitable (between 400 and 700 €/t) if each and every heat exchanger is collected from ELV in less than 10 min time. Their profitability is mostly due to their important weight (> 10 kg/ELV).
- Shock towers show similar trend as bumpers, requiring a long dismantling time for a small mass (dismantling costs estimated between 1800 and 2200 €/t).
- Battery tray on the other hand could prove very profitable (between 200 and 800 €/t), especially because the removal of the battery is mandatory and thanks to their high weight compared to the time needed for their dismantling.

The main lesson is that the economic feasibility of dismantling seems to be related to two main factors:

- The weight of the component (the heavier, the more interesting it is to dismantle)
- The time needed to dismantle.

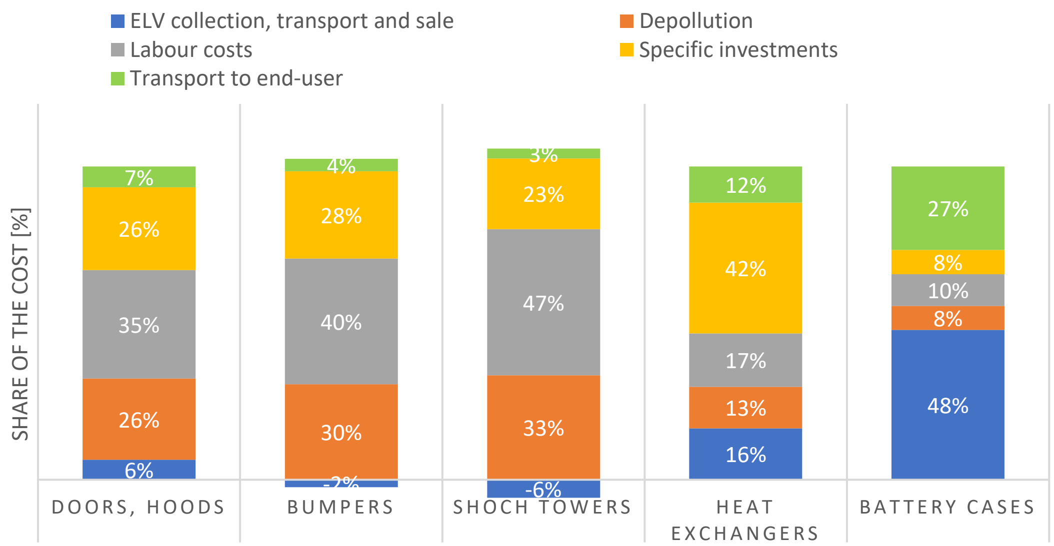

Figure 7: Cost breakdown for each component.

If all the dismantling assumptions used for these calculations are verified on real dismantling tests (especially the investment and labour time), battery cases and heat exchangers could be dismantled economically, however, the quality of the actual scraps produced should be checked before with specific dismantling campaigns, and confronted against aluminium producer specifications. For doors and hoods, it is more difficult to say but, except for the scenario of thorough dismantling which would never be profitable, other scenarios could prove profitable but would let low margin in most of the computed cases. Optimizing the dismantling time, for example with specific operator training could also help reduce the overall costs and thus improve the profitability. Finally, bumpers and shock towers tend to show little profitability.

Conclusions

The information collected during the discussions and interviews indicates that refiners as well as remelters all agree on the interest of accessing to and use more ELV “clean” scrap, for both economic and environmental reasons. From an economic point of view, access more clean scrap could reduce the consumption of primary aluminium or alloying elements and the need for costly preparation steps. From the environmental point of view, this would increase the overall sustainability of aluminium production as less primary metals (aluminium or alloying elements) would be mined and smelted, and enhance closed-loop and local recycling.

Most remelters are interested in very clean scrap as their overall process can’t process contaminated scrap, however, some of them could be open to evolutions in their practices to start closed-loop recycling if the available volumes were significant enough. Concerning the refiners, part of their expertise lies on the preparation and processing of different types of scrap, and thus, although they are interested in accessing new scrap qualities coming from ELV dismantled components, it is important to be careful that the improvement of ELV components dismantling would not impact the volumes and qualities of scrap available for refiners (of mix shredder residues for example). According to our calculations on the global figures of expected aluminium flows from ELV by 2040, due to the increase of aluminium content in cars, this should not be a problem.

From the point of view of the dismantlers, specific components dismantling for recycling is already performed at a small extend and an increase of these practices is possible but the economic viability must be proven and checked at local scale. It thus requires sufficiently high scrap prices and certain levels of collection volumes for the development of the business. To that end, dismantlers would require more data and possibly new and enhanced training (see recommendations section).

Shredders could play their part but few of them actually treat full ELV, most of them only perform the shredding, which is their core business. They could invest in technologies such as destructive tools to remove interesting parts before shredding the ELV, but it requires the ELV carcasses to be “in shape” (not compacted). They could also invest in developing sorting technologies, but they have still little interest for the moment: either an improvement of the dismantling or the post-shredding sorting will require additional costs and specific investment, especially for scrap quality monitoring. Not a priority today since they have no issue selling their shredded residues (in or outside Europe).

From a technical point of view, there remain few issues. Dismantling any component is possible with existing tools, either by hand or via destructive dismantling tools. The separation of component after dismantling can be performed using mobile alloy identification tools (spectrometer) which would of course require additional investment for the dismantlers. However, for big components containing multiple alloys (mostly hang-on parts, battery trays), current technologies (X-ray, LIBS) would require further development and testing. Finally, at refiners and remelters, there is no technical issues as many technologies are currently used and allow the process of any kind of scrap. However, remelters would only be able to process very clean scrap, which means that actual scrap quality produced by ELV component would have to be tested first.

From an economic point of view, the results of the economic assessment performed for 7 shortlisted components indicate that the two main drivers of the dismantling costs are the dismantling time (associated to labour costs and specific investment costs) as well as the weight of the component to be removed. Indeed, dismantling could be profitable for heavy components (> 10 kg) which would require less than 5 min dismantling time. For lighter components, and components which are difficult to access, dismantling will hardly be profitable. However, these conclusions strongly depends on the market prices (aluminium and ferrous scrap), future evolutions could render some of these practices possible.

Finally, from an overall flow and logistical point of view, there is globally, at European scale a potential for a significant increase in the volumes of dismantled components by 2040 (multiply by 2 to 3). However, at local scale, ATF scale, the current volumes of aluminium possible to access and dismantle are quite low. For example, in France, on average an ATF could not gather more than a few hundred kilos of wrought aluminium per year. Plus, given the choice and because of their values, dismantlers will always choose to dismantle component for re-use than for recycling: increase use of aluminium in cars, will also lead to increase need for aluminium parts for re-use, reducing the amount available for recycling. This means that there is a need for massification or the development of regional strategies between ATF, ATF networks and shredders, with, for example, collection scheme and centralized processing (storage/shredding/sorting).

Recommendations

According to dismantling experts, increasing the dismantling rates of specific components is not an issue of technical feasibility and no new specific equipment would be needed, but rather an issue of economics, information and training. ATF (and shredders performing dismantling) could use technical data from OEMs such as:

- List of materials and alloys used in metallic components,
- Best practices for dismantling specific components, for each car model. This type of information should be based on common work performed by dismantlers and OEMs together,
- Existing recycling route.

If additional data were to be provided by OEMs, for example in systems such as IDIS, dismantlers will then need training: to be taught how to use the additional data and to understand the financial benefit this will bring them if they process different alloys independently.

IDIS system could be significantly improved, as it is currently little used for dismantling purposes: because of the lack of useful data (from dismantling point of view), but also because of the complexity of the tool. A simplification of its utilisation would be welcome and would help increase its utilisation by dismantlers.

Dismantling experts agree on the fact that specific trainings focused on the dismantling for recycling, and also enhanced general training on dismantling are key to optimize dismantling practices, dismantling time and thus improve the profitability of the process. This kind of training should include information on aluminium alloys specifically: which type of components/alloys can be separated visually (cast alloy components from wrought) or which alloys/components could be stored/mixed together, which alloys should not.

Dismantlers, shredders and dismantler networks need to know more about the volumes of aluminium available and expected in which components, from which type of car (brands, segment markets), in order to assess the actual feasibility of dismantling, not over a single dismantling site, but over a whole region or a country. Such knowledge could help creating specific recycling branch or mutualization strategies with ATF network/shredders.

The battery case presents the highest potential of the all investigated components, because it is a heavy component whose end-of-life regulation require dismantling during the depollution process. It is however associated to a very specific challenge as its end-of-life process is not well defined yet: who should extract the battery cells from the battery case between the dismantlers, the battery recyclers or OEMs, and thus who can recover the battery case and its high economic value. It is also important to note that with the rising number of electric vehicles, this kind of component will have a higher economic value for re-use and their dismantling, which will probably restrain the volumes available for recycling.

For the shredders, as buyers of ELV carcasses, they would be impacted by an increase of dismantling for recycling, and they would need to make sure that the carcass price is adjusted to the level of dismantling performed by their suppliers: the more metallic components are removed at dismantler, the less should the carcass cost, and the type of metal should be taken into account (whether it is steel, aluminium or copper).

As the performances of alloy-to-alloy sorting technologies (such as X-Ray/LIBS) are not sufficient yet for post-consumer scrap, improvements could be made at OEMs and aluminium producer level to simplify the end-of-life separation process by working on alloy development to make aluminium alloys more tolerant to recycled material and by working with OEMs to improve recyclability already at the design phase.

More generally, one last recommendation all actors of the aluminium value chains agree on is the increase of the collection rates of ELV, especially for premium vehicles. Avoiding the loss of such vehicles and ensuring their treatment in Europe could increase significantly the amount of aluminium recovered each year (aluminium flows in vehicle of unknown whereabouts are of the same order of magnitude as the flows of aluminium actually recovered), and also guarantee clean depollution and disposal of depolluted elements.

Finally, specific dismantling and shredding campaigns should be performed to verify the technical and economic feasibility on a well-defined sample of relevant components and compare the quality of the actual aluminium scrap produced (Hex, battery trays, hang-on parts) against remelters and refiners' requirements.

List of abbreviations

ATF	Authorized Treatment Facility
ASI	Aluminium Stewardship Initiative
BEV	Battery Electric Vehicle
CoD	Certificate of Destruction
DMFA	Dynamic Material Flow Analysis
ELV	End of Life Vehicle
EoL	End of Life
EPD	Environmental Product Declaration
EPR	Extended Producer Responsibility
HPDC	High Pressure Die Casting
HSR	Heavy Shredder Residues
ICE	Internal Combustion Engine
IDIS	International Dismantling Information System
ISRI	Institute of Scrap Recycling Industries
LCV	Light Commercial Vehicles
LME	London Metal Exchange
MB	Metal Bulletin
MFA	Material Flow Analysis
OEM	Original Equipment Manufacturer – car manufacturers
PHEV	Plug-in Hybrid Electric Vehicle
UK	United Kingdom
VDC	Vacuum Die Casting

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