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SEES

Sustainable Electrical & Electronic System for the Automotive Sector

Specific Targeted Research or Innovation Project
(STREP)

Priority 6.2: Sustainable surface transport

D6: Car Shredding Manuals

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Glossary

ARN	Auto Recycling Nederland BV
ELV	End-of-life-Vehicles
EES	Electrical and Electronic System
PCBs	Printed Circuit Boards
ASR	Automotive Shredding Residues
SLF	Shredder Light Fraction
ECRIS	Environmental Car Recycling in Scandinavia (project)
ACEA	Association des Constructeurs Européens d' Automobiles
LUA	Landesumweltamt
MOE	Ministry of the Environment
FhG-ICT	Fraunhofer Institute for Chemical Technology
WKÖ	Wirtschaftskammer Österreich
EAF	Electric Arc Furnace
BOF	Basic Oxygen Furnace

1 Introduction / Summary of WP 6

WP6 – Shredding Study analyses the shredding process of end-of-life vehicles (ELV) with a special view on the parts of the electrical and electronic system (EES) that remain in the car. The relevant contents of EES are cables, spools, copper in general, other metals, printed circuit boards (PCBs), plastics. It is investigated which of the materials go to which fractions and what are the influences to further recycling processes, disposal and costs/revenues.

Activities (see also description of work):

- Quantification and characterisation of the fractions obtained in the shredding process.
- Definition of the quantity of the material from the car EES that goes to each fraction
- Quantification of revenue reductions if the copper goes with the steel fraction to steel recycling
- Investigation in optimal dismantling level before shredding
- Definition of requirements on logistics
- ASR material supply for WP5

The results of WP6 should especially contain useful information for product designers (design for shredding), suggestions for optimisation of the shredding process and the definition of an optimum scenario (ecological and economic).

2 Methodology

2.1 Transport Aspects for ELV

For dismantling EES good access to all compartments of the car is necessary. At the moment cars are transported in container trucks with as many cars as possible in the containers. The cars are typically damaged in this case and dismantling EES especially from the interior its hardly possible afterwards. 3 different scenarios are analyzed to receive results whether an alternative is preferable:

Scenario 1 – transport on container trucks, as many cars as possible

Scenario 2 – transport on container trucks, avoiding damage to the cars

Scenario 3 – transport on special trucks as they are used for new cars

2.2 Shredding Tests

Shredding tests were carried out at two shredder facilities of Mueller-Guttenbrunn in Amstetten (Austria) and Budapest (Hungary) to obtain results from different ELV inputs (Amstetten – ELV from Central and Western Europe, Budapest – ELV from Eastern Europe).

Following data was documented to receive relevant information about the shredding tests:

- ELV-data (Incoming weight, manufacturer, type)
- Depollution and standard dismantling (weight of fractions, time)
- Weight of depolluted and dismantled cars = shredder input
- Estimated weight of remaining relevant EES in the cars
- Shredding process (weight of obtained fractions, time)
- Hand-picking analysis of the shredder fractions

The results of the shredding tests are compared to a theoretical scenario where EES is completely dismantled before. Especially quality aspects of the steel and waste fractions are proved as well as the cost-revenue-balance of the different scenarios.

2.2.1 Collection of cars

Regarding the representative figures of used cars in Europe we choose the following table, for collecting the cars for the two shredding trials in Amstetten. The numbers should be representative for Europe. We developed a representative scheme already in M9 (Table 1).

Table 1: Plan for the collection of cars as samples for the shredding tests in Amstetten

Manufacturer	Existing cars 2003, Austria	[%]	Number of cars for trial
VW	824,208	20.4	6
OPEL	407,786	10.1	3
FORD	304,398	7.5	2
RENAULT	229,229	5.7	2
AUDI	221,506	5.5	2
MAZDA	220,152	5.4	2
MERCEDES	202,969	5.0	2
TOYOTA	199,259	4.9	1
PEUGEOT	166,772	4.1	1
BMW	161,866	4.0	1
FIAT	144,115	3.6	1
NISSAN	123,551	3.1	1
others	839,497	20.8	6
overall	**4,045,308**	**100.0**	**30**

If any of these cars have not been available, other cars were taken as substitute.

In Budapest we had to deal with random cars – because there hardly ever arrive complete and suited cars at the shredder because usually several parts are disassembled before the ELV arrive at the shredder.

2.2.2 Depollution

The chosen ELV for the shredding tests were depolluted and dismantled after normal standards.

Following fractions were separated in the depollution and dismantling process

- oil
- fuels
- battery
- catalytic converter
- rubber from tyres
- rims
- lead from tyres
- valves from tyres
- brake liquid
- cooling liquid
- window cleaning liquid

All of the fractions were weighed and the recycling/reuse/disposal possibilities were proved.

2.2.3 Estimation of remaining ESS

Based on the information from the WP3 “Disassembly Study” the weight of the remaining EES in the car was estimated to receive comparable numbers between EES input and EES output to the different fractions.

2.2.4 Shredding process

The shredder and its boxes and conveyor belts were emptied before the test for not mixing the material from the ELV with remaining material from other sources.

Each obtained fraction – was weighed and a representative sample for a handpicking analysis was taken to see exactly the contents.

3 Shredding technologies

3.1 General information on shredding technologies

The shredding of automobiles (and major household appliances) is a process where at the heart of the shredder, a hammer mill acts as a giant tree chipper by grinding the materials fed into it to fist-size pieces. The shredding of automobiles results in a mixture of ferrous metal (*e.g.,* iron-containing scrap), non-ferrous metal (*e.g.,* alloys of copper and aluminium), and shredder waste.

These constituents are separated by a variety of methods, generally on-site. The ferrous and the non-ferrous metals, the so-called shredder heavy fraction, can be sold to secondary metal smelters where they are recycled into new products. Shredder waste consists of glass, fibre, rubber, plastics, and dirt. This shredder waste is sometimes differentiated into shredder light fraction (SLF) and dust. For automobile shredders, the SLF makes about 25 % of the output weight. Modern shredder plants will have dust cleaning equipment such as cyclones or bag filters (in fewer cases). A schematic drawing of a shredder process is given in next figure.

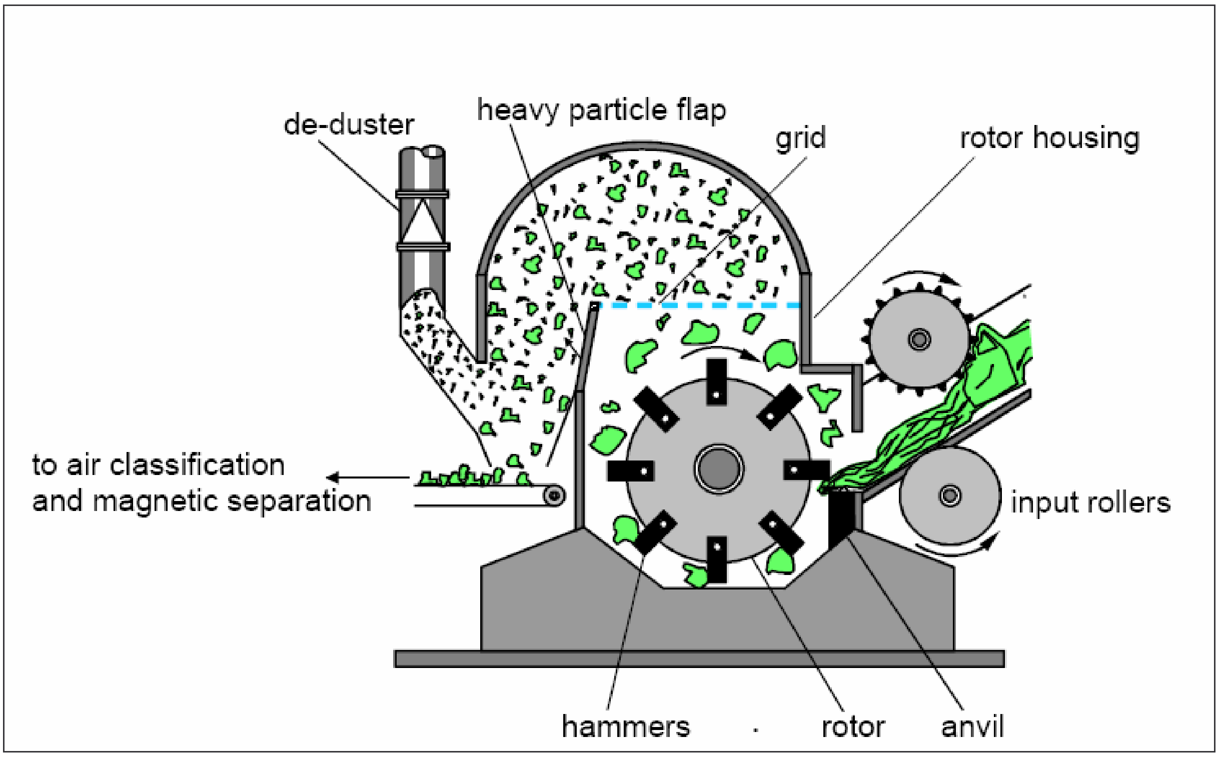

Figure 1: Hammer mill shredder plant for cars [Gotthelf 1996]

ASR often contains hazardous substances such as lead, cadmium, and PCB. Therefore, some countries have classified ASR as hazardous waste and have established legislative controls. There is not much information available as to the occurrence of dioxins (PCDD/PCDF) in the shredder process and to our knowledge there are no studies as to the formation of PCDD/PCDF within the process.

Automobile Shredders

Hammer mills – often called automobile shredders but used to shred other materials as well – break up material using huge hammers attached to a rotor. Capacities generally range from 5 horsepower to 6,000 horsepower.(Cooker, 2004)

These multi-purpose, heavy-duty machines are suitable for processing materials such as ferrous and nonferrous turnings, aluminium cans, aluminium scrap, ferrous scrap such as sheet iron, automobiles and white goods, along with non-metallic material such as chemicals, coal, limestone, firebrick, asphalt and shingles. They are typically used in scrap yards, resource recovery plants, municipal solid waste facilities, refineries and smelters.

The hammer mill breaks up products, separating ferrous from nonferrous material, which can be further separated using downstream processing equipment such as magnets, cleaning systems and dense media systems.

The hammer mill is generally four-armed, with heavy-duty swing hammers that can be reversed for wear. The units are generally furnished with outboard flywheels for pulling them through any surge load periods.

These machines can be diesel driven or electrically powered, and can have alternating current (AC) motors or direct current (DC) motors. The larger units have circulating oil for the bearings. Hammer mills are generally opened hydraulically for quick and easy access to the interior of the machine without disturbing the feed hopper during maintenance and inspection.

For scrap applications, larger machines generally use manganese or T-1 liners. And in the larger machines, reject doors in the back upper housing are furnished for ejecting unshreddable items.

Hammer mills (without motor or associated systems) generally range in price from €7.500 to €1.25 million depending upon the capacities, the material to be processed and the product size required.

While it’s true that hammer mills are noisier than shear type shredders and they create more dust, this is more than offset by the higher capacity, lower maintenance and reduced down time. Many hammer mills have been in service for fifty years and are still going.

There are also double rotor hammer mills which can take the material discharged from the primary hammer mill and grind it to a smaller size.

Shredder Systems Overview

Shredder systems today are basically divided into four different sections: the shredder drive (motor), the infeed conveyor, the shredder and feed device and downstream cleaning equipment.(Mullins, 2004)

Shredder Drive

Two basic types of alternating current (AC) motors have been used to drive shredders for the past three decades – a squirrel cage design and a wound rotor type. Both types do an effective job of shredding, but the wound rotor motor tends to have a longer life span and a lower energy demand. The wound rotor motor is more expensive initially, but adds value through time due to the longer life and the lower power costs.

In the 1990s, direct current (DC) motors have come into use for shredders. The DC motor offers processors the ability to regulate rotations per minute (RPMs), which is an advantage, but many in the industry feel that the control package still needs to be refined. It has now been proven that running shredder motors at lower RPMs creates numerous advantages from the older higher RPM motors. The lower RPMs create more torque, which allows for more effective shredding, yielding better production, longer life for parts and lower overall shredding costs.

Infeed Conveyor

The typical infeed conveyor for a shredder is a heavy-duty steel track conveyor. The conveyor is generally built using wide flange beams, I-beams, rectangular tubing, heavy channel, heavy angle and ½" plate skirting. There is a horizontal loading section and a horizontal section at the head of the conveyor. The typical drives are hydraulic, for variable speed, but electric drives can also be used.

Shredder and Feed Device

The typical automobile shredder is designed to process a wide variety of materials, including whole or flattened cars (without gas tanks), miscellaneous loose appliances, and a wide range of scrap.

Some feeding devices are designed with a 35-degree feed angle. This is steep enough for all types of scrap to slide down easily. If it is steeper, there are additional costs since the infeed conveyor must be longer. Grouser bars run the length of the chute and a replaceable section is provided underneath the feedrolls. The double feedroll is often the preferred way to feed the shredder.

Downstream Cleaning System

The undermill vibrator carries the scrap from the shredder to the first transfer conveyor. Rotary electric drives for the undermill vibrator have proven to be beneficial because they are generally low-maintenance and are sturdy enough to handle explosions. Generally, most conveyors have a flat design, allowing for a thinner depth burden, which makes it easier to clean the product.

The typical system has from one to three drum magnets – the wider, the better – for separating ferrous material from nonferrous. These drum magnets can be a radial design or an axial design. Usually a picking vibrator/oscillator or conveyor follows the magnets, allowing for hand picking. This will feed a radial stacker, which can stockpile material or feed it directly into trucks or railcars.

Generally the remaining material then passes through some type of ferrous recovery magnet (cross belt or magnetic head pulley), and a screening device such as a trommel to capture the fine fraction. Eddy current separators are then usually used to separate the nonferrous metals from the stream.

Several shredder systems are shown in the next figures:

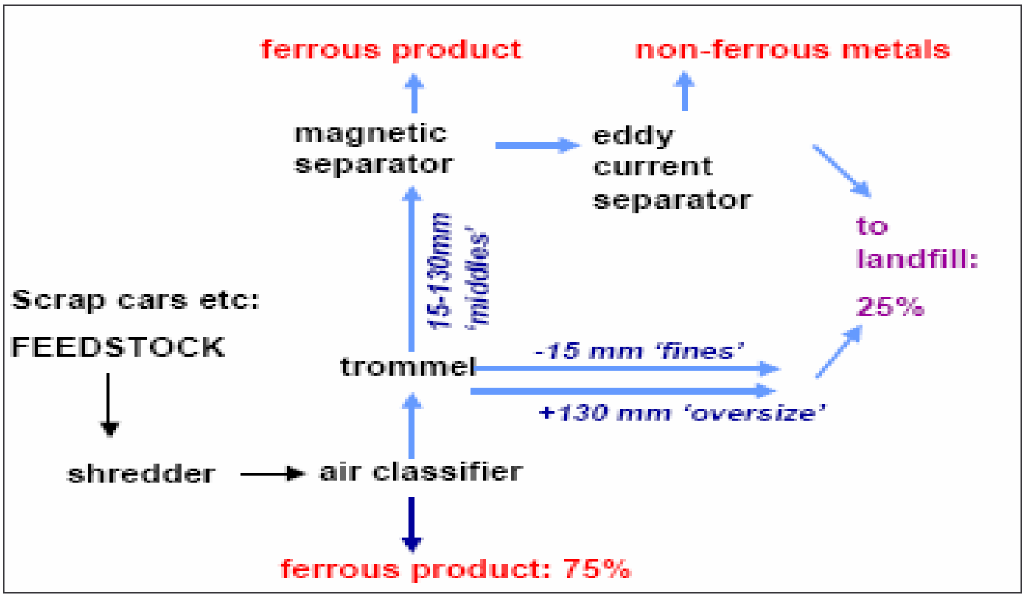

Figure 2: Basic flow streams in a shredder Source: [Harder 2001]

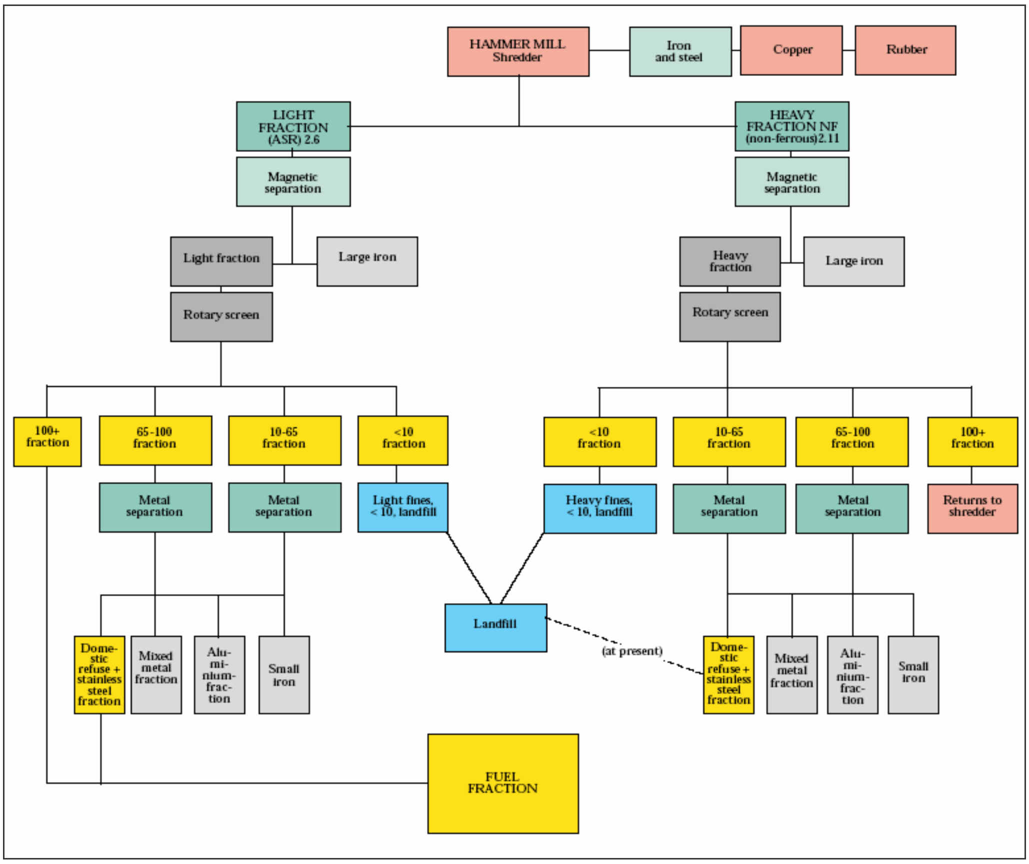

Figure 3: Flow chart of a shredding process at Gotthard Nilsson, Hallstahammar, Sweden Source: [ECRIS Project 1994-1998]

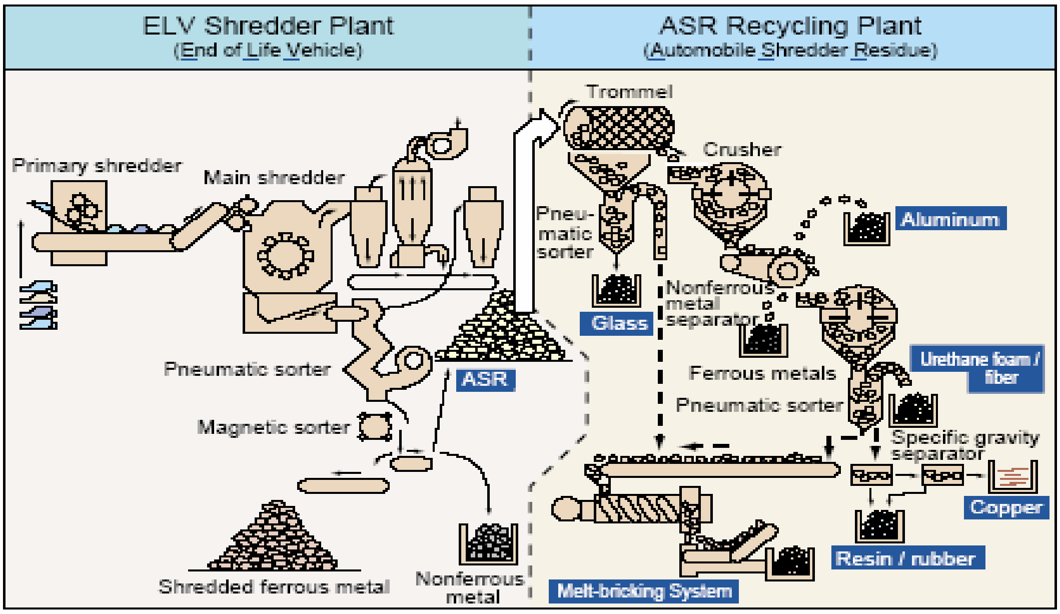

Figure 4: Shredder plant at Toyota. Source: [Toyota 1999]

3.2 Technology description of the shredders at Mueller-Guttenbrunn

This section describes the shredder equipment that has been used for the shredding tests in WP6. The big car shredder of the “metals recycling GmbH” in Amstetten has a performance around a 1000-kW-Shredder. Contrary to the wide-spread classical shredders it has no grid and it can cut selectively. The material is not pressed as with other shredders by a defined opening (e.g. 100x80 mm) but can leave the shredder if it is not bigger than defined (see sketch down right).

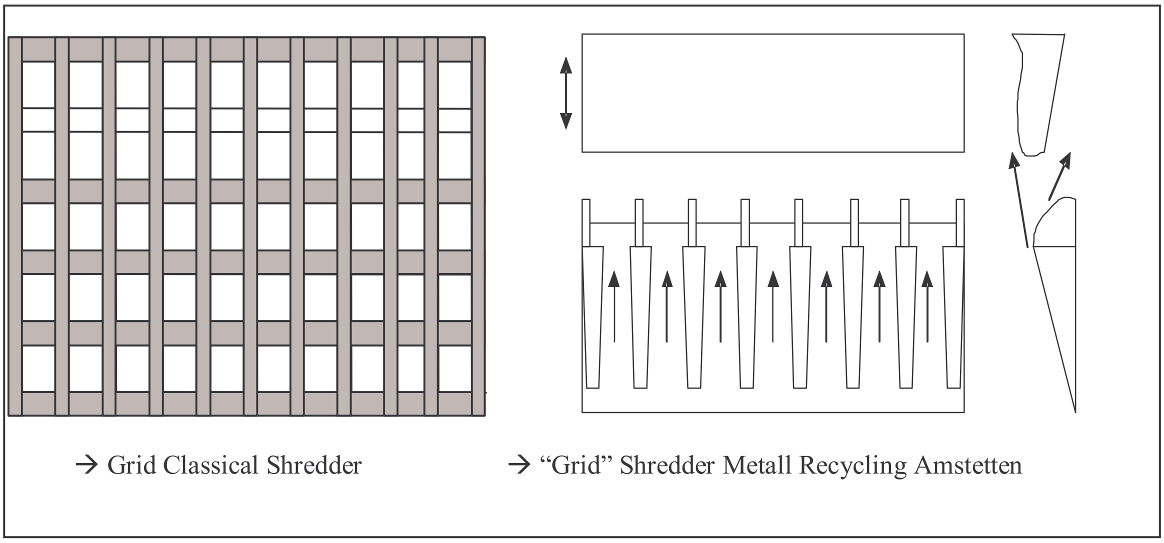

Figure 5: Shredder details at Müller-Guttenbrunn Source: [Müller-Guttenbrunn 2004]

After cutting an air separation is following where the heavy fraction (all metals, stones, glass, rubber, plastics) is separated from the light fraction (all dust, foam material, textile...).

From the light fraction first with the help of a transferring magnet the rougher iron portions are separated. Afterwards the remaining shredder light fraction at a magnetic tape role is separated into a magnetic and a non-magnetic group.

The magnetic light group is eliminated at time in the incineration plant, the non-magnetic group is still prepared in the METRAN separation plant and approx. 10 % metals from it is recycled.

The heavy group is separated at a magnetic drum into an iron and a non ferrous-fraction. The iron group is cleaned manually from copper hooking and/or textile and rubber parts, so that the scrap finished thereafter corresponds to the requirements of the customers (in accordance with scrap iron local list). The Shredder NE with the possibly contained condensers is isolated in the METRAN into the individual components.

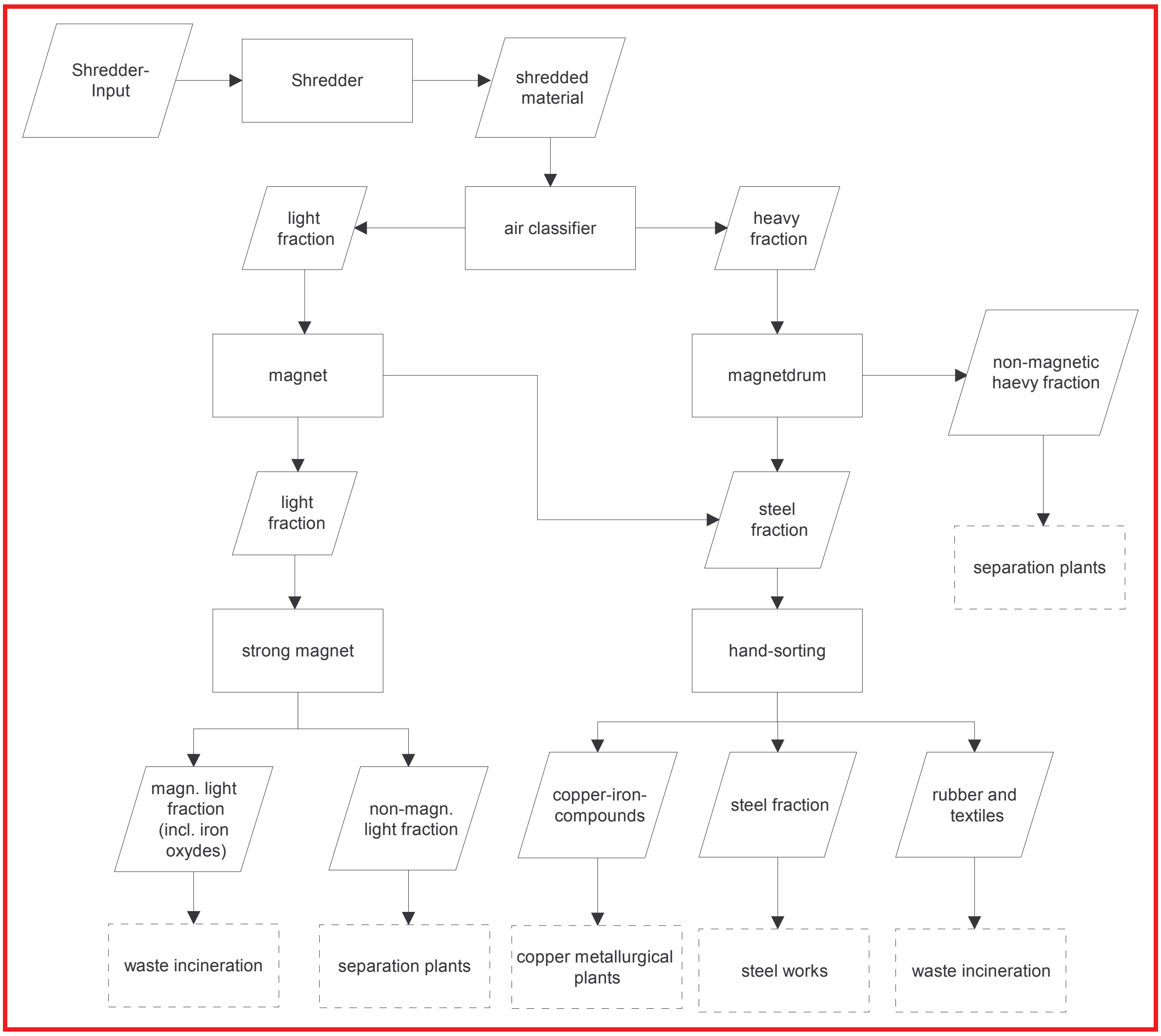

Figure 6: Shredder flow chart for Müller-Guttenbrunn, Amstetten.
Source: [Müller-Guttenbrunn 2004]

4 Recycling of cars

Recycling of ELV incorporates the recycling itself, recovery, and reuse. The driving force, criteria, and concept for ELV recycling result from different factors that have changed with time.

- The development of the electric arc furnace in the 1960s–1970s dramatically increased the use of vehicle shells as input scrap.
- The production of high-quality steel required the use of vehicle scrap free of nonferrous metals, prompting the magnetic separation of ferrous from non-ferrous metals.
- The separation and recovery of aluminium from ELV was more energy efficient than production of aluminium from its ores.
- Today, recycling of ELV is driven not only by economic and technological factors but also by social and environmental concerns. In other words, the automobile industry is shifting toward sustainable waste management.

Recycling options for ELV are related to the material used for vehicle manufacturing as well as the assembly of its components. The use of lighter materials (aluminium, magnesium and plastics) improved fuel economy and reduced emissions. It is believed that a 100 kg weight reduction of a vehicle results in a fuel savings of about 0.7 L/100 km.

However, introducing lighter materials to vehicles also compensates for weight increases resulting from new comfort and safety features and has implications and effects to the car recycling.

4.1 Selected European Legislation

Directive 2000/53/EC of 18 September 2000 established a legally binding instrument and lays down measures which aim, as first priority, at the prevention of waste from vehicles, and in addition, at the reuse, recycling and other forms of recovery of ELV and their components in order to reduce the disposal of waste and to improve environmental performance. The Directive covers vehicles and end-of-life vehicles including their components and materials. It promotes the prevention of waste and calls on manufacturers that all vehicles placed on the market after 1 July 2003 do not contain non-exempted lead, mercury, cadmium, or hexavalent chromium (there are exemptions).

The Directive includes provisions for the set-up of collection systems for ELVs and authorized treatment facilities. A certificate of destruction is a prerequisite for deregistration of the vehicle. Member States shall take the necessary measures to ensure that ELV are stored and treated in accordance with existing legislation (Article 4 of Directive 75/442/EEC). Treatment operations should include stripping of ELV before further treatment, removal and segregation of hazardous materials, pre-treatment should be performed to ensure the suitability of vehicle components for reuse and recovery, especially for recycling. Reuse and recovery should be encouraged.

The current situation in the EU is summarized in next Table.

Table 2: ELV legislation and EU ELV Directive Implementation [ACEA 2004]

COUNTRY	Existing Legislation	Directive Implementation Status	Requirements deviating from Directive
Austria	Ordinances issued 11/2002 based on Waste Management Act 2002; Voluntary Agreement (1992)	Implemented	Economic operators not specified; Main tasks placed exclusively on manufacturers / importers; extreme complex report duties
Belgium	Voluntary Agreement 1999; Renewal Voluntary Agreement in negotiation Regional legislation: Flanders 1999, Brussels 2002 and Wallonia 2003	Implemented in the 3 Regions except art. 4 § 2 and 8 § 1 (Federal competence):	Free take back by 01.01.2006 on the condition of a progressive management plan approved by different administrations before 01.07.2004
Denmark	Consolidation Acts 373 & 860 (1999); Executive Order 141 (2000)	Modification of Executive Order published 19.06.02, covering the period until end of 2006	As defined in "car package" (treatment, requirements to companies, compensation)
Finland	No	In preparation (30.09.01)	Nil
France	Voluntary Agreement (1993)	The French ELV transcription decree has been sent to the council the 13th of March for adoption. (Decree N° 10)	Research: Increase recoverability (2002 90%) & recyclates use; Parts marking; Information
Germany	Legislation (Altauto VO)	Implemented since 01 July 2002	Last owners deliver ELVs to certified dismantlers. Recovery quota. Cost-free take back. Technical requirem. for dismantlers.
Greece	General Waste Law	Legislation expected not before mid January 04	Athens & Thessaloniki : Cost free take back 01 Jan. 2004
Ireland	Voluntary Agree. in discussion commencing 09/01	2nd draft available	None
Italy	National and regional laws	Adoption foreseen before July 2003	ELV owners deliver ELVs to authorised centres – Car makers are free to create a free-take back network. If they do so they are allowed to guarantee free-take back only if their vehicles are delivered to one of these authorised centre.
Luxembourg	General waste law only	Law implemented 01 April 2003	None, however producers are responsible for Monitoring
Netherlands	Special body created by 5 organisations: ARN (1993)	Implemented since 04 June 2002	Dutch Government has brought forward the EU 2015 targets to 2007 and 2006 to 2003
Norway	Governmental System (1978)	Implemented since 16 July 2002	As per ELV Directive
Portugal	Scrap Yard Decree (!998) and Voluntary Agreement (1999)	3 rd. Draft dated 15.03.03	Management integrated system should (must?) be organised, transport and treatment costs must be borne by producers if negative market values appear.
Spain	Legislation (RD 1383/2002)	Issued 03.01.03	Owners deliver ELVs to authorized centres. Producers shall take back ELVs. Negative market values from 1.1.07 if deficit in treatment chain audited by third party. Recovery quotas.
Sweden	Car scrapping legislation (1975) Producer responsibility ordinance (1998) Regulation on vehicle dismantling operation (April 2002) Government bill (May 2003) Ban of certain metals (Kuly 2003)	Remaining issues: Cost-free take back 2007, Article 9.2	Car Industry responsible for targets & reports for all cars and for free take-back (cars registered Jan 98)
UK	Statutory instrument 2003 No. 2635	In effect 3 November 2003	

4.2 Country situations

According to several estimations in the year 2003 worldwide there were ca. 700 shredder plants. Of these only 43 were certified according to the Ordinance for end-of-life vehicles [LUA 2003].

In the United States, approximately 10 to 12 million automobiles are recycled every year, in Japan, about 5 million of ELV have been annually discharged and they are recycled and treated by dismantling and shredding [MOE 2003].

In the EU 7,530,000 ELV have been treated in 2000 as shown in the figures [ACEA 2004].

An overview about the infrastructure in the European ELV-sector is given in the following tables and figures.

Table 3: ELV recycling infrastructure in Europe. Source [EFR 2002]

MEMBER STATE	Dismantlers (estimated	De-pollution facilities (estimated	Shredder plants Shredding ELVs	Media separation plants
Austria	248	248	6	1
Belgium	450	11	12(2)	5
Denmark	250	250	6	1
Finland	150	25	3	1
France	900	450	42(16)	7
Germany	1143	1143	40(5)	8
Greece	nk	nk	3	0
Ireland	est. 250	nk	4	0
Italy	est. 1800	1800	16	6
Luxembourg	nk	nk	0	0
Netherlands	700	265	10	2
Portugal	nk	nk	2	0
Spain	1500	110	22(4)	5
Sweden	790	790	5	1
United Kingdom	3600	nk	37	4
Norway	100	nk	4	1

Figures in brackets are estimated numbers of pre-shredders

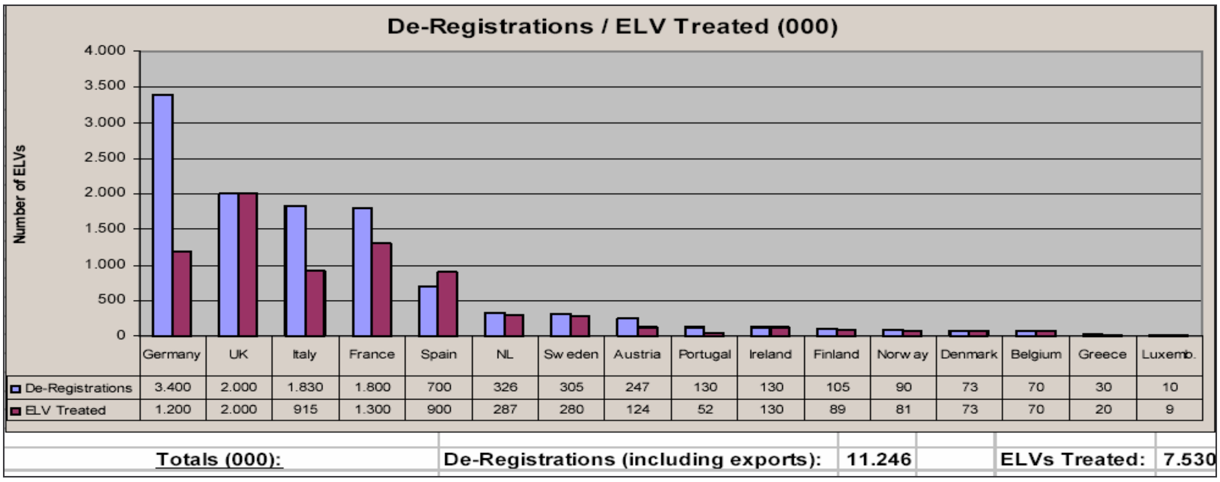

Figure 7: De-registration and ELV treated in EU Member States plus Norway. Source [ACEA 2004]

In Germany in 2001, 3.023.777 passenger cars were taken out of use; of these between 1.1 and 1.7 million cars can be considered ELV [FhG-ICT 2003]. In the EU Member States it is assumed that 8-9 million tons of wastes are generated from ELV [EC 2000].

4.2.1 Austria

In Austria there are six shredder plants in five provinces. In 2002, 212.500 motor vehicles were taken out of use of which, 129.063 were dismantled in the shredder plants. The mass balance is given in the next table.

Table 4: Mass of input and outputs of Austrian shredder plants in 2002. Source [WKÖ 2002]

Input/Output	Total Mass from Six Shredder Plants Combined	
ELV shredder input	98,400 t	100 %
Fe-scrap from ELV	70,900 t	72 %
Non-Fe scrap from ELV	4,900 t	5 %
Shredder waste from ELV	22,600 t	23 %

The EU directive on end-of-life vehicles (ELV) was passed in September 2000. The directive gives the Member States an obligation to ensure the collection and proper treatment of ELV. The costs related to the collection and treatment of ELV are mainly to be paid by the producers of the vehicles.

In Austria, most of the conditions of the directive are already fulfilled. Since 1992, Austria has a programme on the take-back of ELV. The programme is a voluntary agreement between the motor vehicle industry, the Federal Ministry of the Economy and the Federal Ministry of Environment, Youth and Family Affairs.

As a result of the agreement, Austrian ELV are free of charge taken back from the customer upon simultaneous purchase of a new or a used vehicle. This agreement originally expired in 1995, but was subsequently extended for an indefinite period of time and further expanded by additions to prevent improper disposal. The expansion concerns in particular:

- the establishment of ’minimum requirements for the recovery of ELV’;
- issuing of a certificate of proof of recovery for the vehicles final owner.

In order to be approved as an official receiving facility for ELV, companies have to sign the voluntary agreement. A total of 1 325 Austrian companies had signed the agreement. Currently, the agreement’s expanded contents have not been sufficiently implemented and documented.

As can be seen in the table below, the number of de-registered cars in Austria has increased from approximately 160 000 in 1993 to just under 200 000 in 1999. According to the actual research, the number of ELV treated in Austria was just under 100 000 in 1997–99, which is less than 50 % of the potential. However, the remaining 100 000 vehicles are supposed to be exported to other countries.

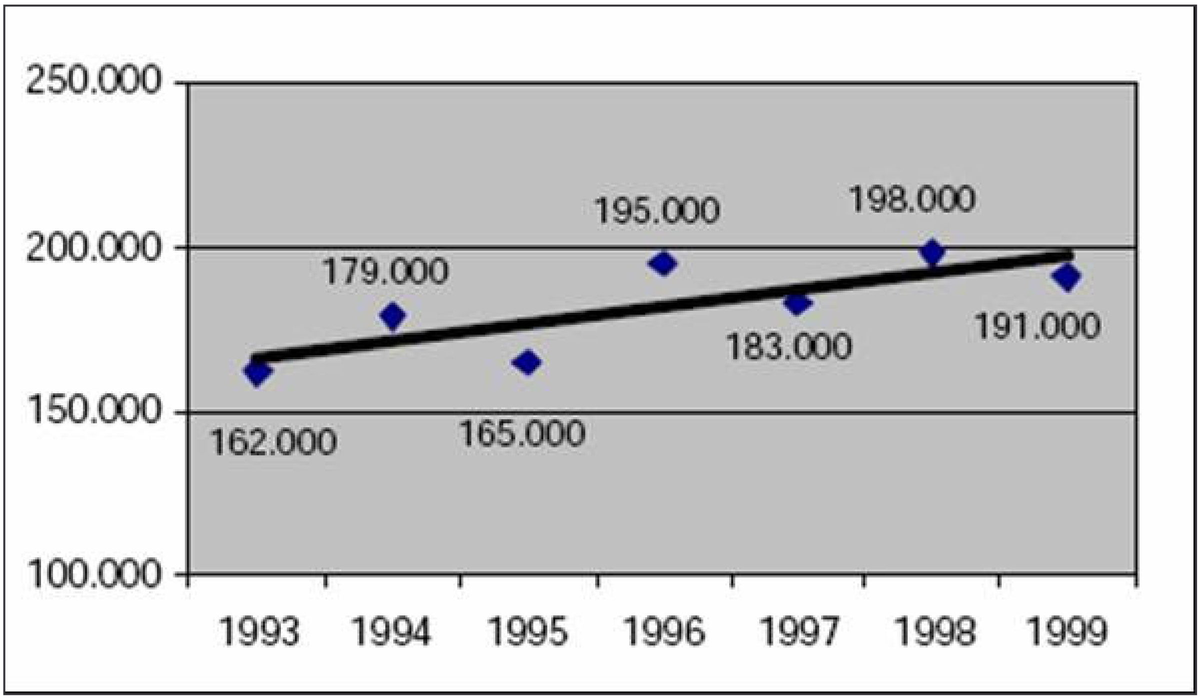

Figure 8: Number of ELVs recycled in Austria, 1993 to 1999 [WKÖ 1999]

Due to the supposed large export of vehicles it is very difficult to evaluate the precise recycling quota for cars in Austria. Illegal disposals do occur and in these cases municipalities finance recovery and disposal. When it is presumed that most of the cars not recycled in Austria are exported for continuous use, Austria is very close to the fulfilment of the first target in the EU directive on ELV. The targets of the directive are:

- not later than 1 January 2006, at least 85 % of the ELV are to be reused/recovered and at least 80 % are to be reused/recycled;
- not later than 1 January 2015, at least 95 % of the ELV are to be reused/recovered and at least 85 % are to be reused/recycled (targets currently under revision).

As a result of the take-back commitment, car disposal is free of charge for the consumer in the case of a simultaneous purchase of a new or a used vehicle. According to the Austrian Federal Environmental Agency more than half of all take-back actions, however, were not connected to a purchase of a new vehicle and therefore the last holder paid for recovery and disposal.

Due to the agreement on the take-back of end-of-life vehicles, most cars discarded in Austria appear to be collected and treated in an environmentally friendly manner. However, the data on car disposal in Austria is connected with some uncertainties because a large proportion of de-registered cars are exported. Therefore, it is not yet possible to evaluate the exact effects of the initiative.

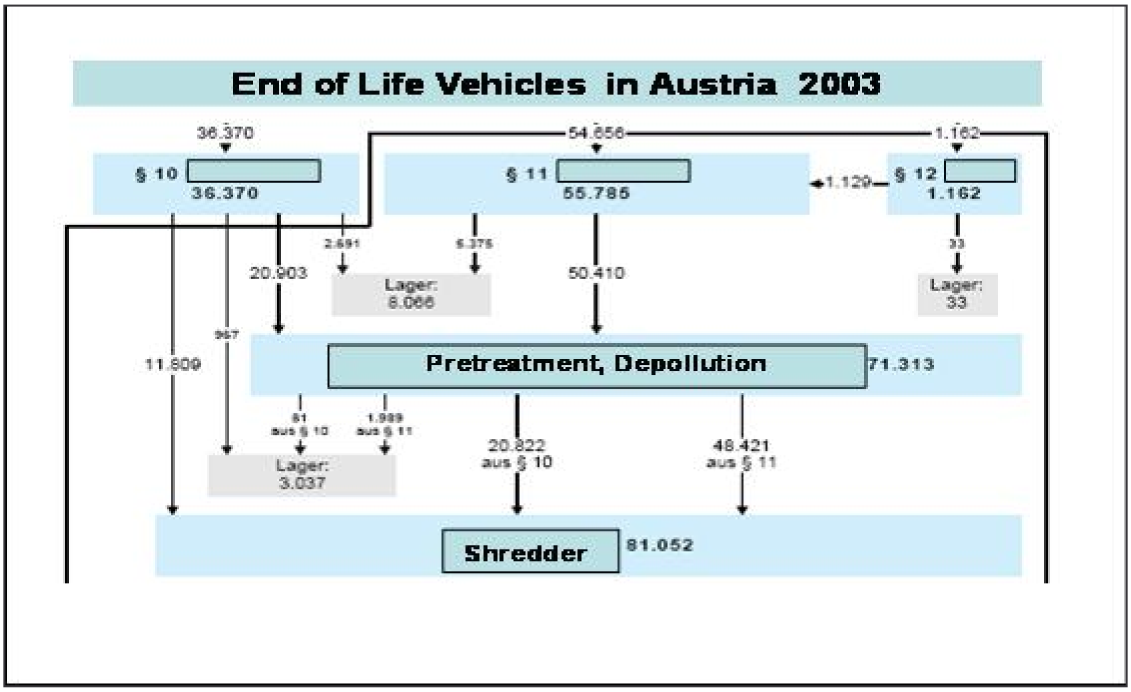

Figure 9: Flow of ELVs in Austria 2003. Source: [Altauto 2004]
(§§ 10, 11 and 12 are related to the Austrian law)

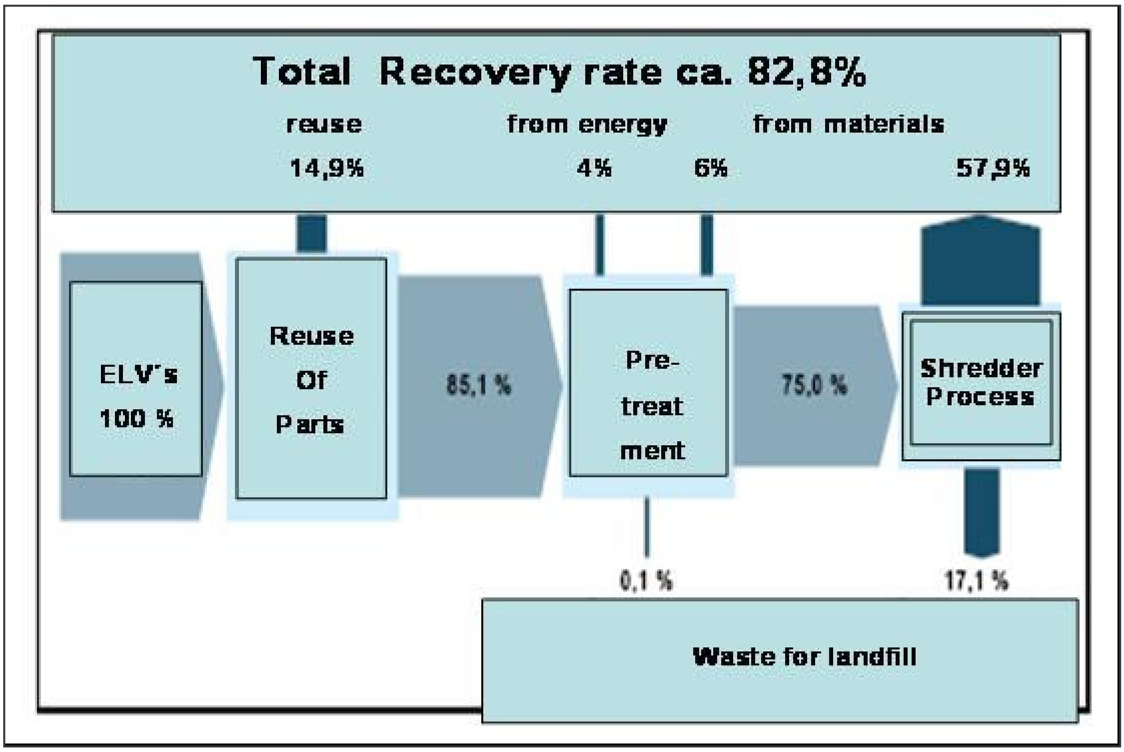

Figure 10: Recovery rate of ELV in Austria 2003. Source [Altauto 2004]

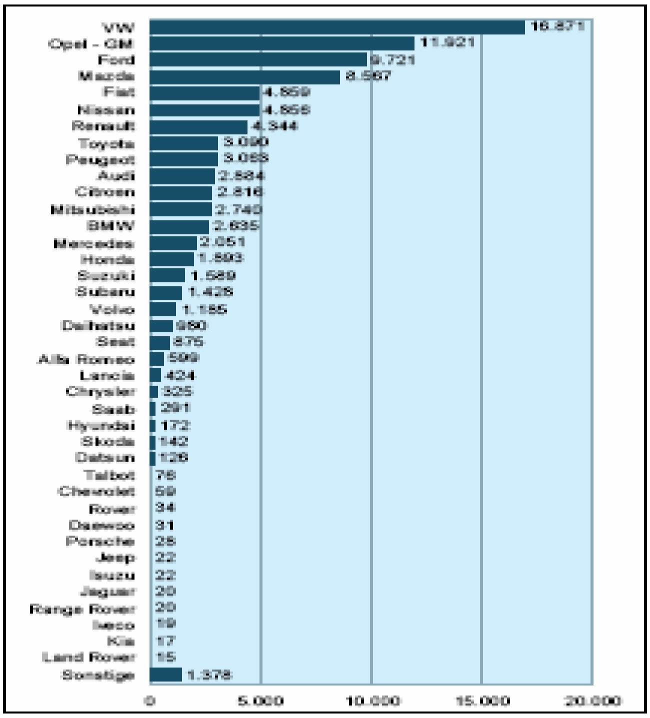

Figure 11: Manufacturers of ELV in Austria [Altauto 2004]

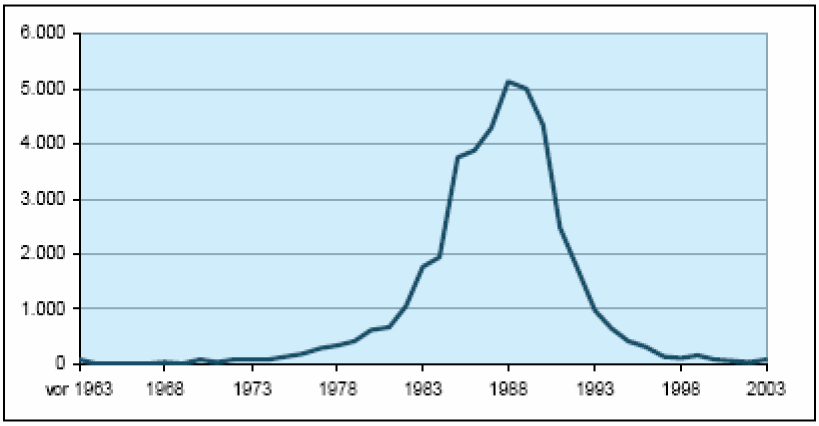

Figure 12: Year of construction of the ELV in Austria in 2003 [Altauto 2004]

4.2.2 Netherlands

In the Netherlands some 300,000 vehicles are discarded every year. In general they end up at a car dismantling company. The car industry set up the Auto & Recycling Foundation. To implement the concept described above, Auto Recycling Nederland BV (ARN) is responsible. The Auto & Recycling Foundation owns the shares in this limited company.

ARN has concluded contracts with car dismantling companies that dismantle car materials. ARN also collaborates with collection companies that transport the dismantled materials to contracted recycling companies. In addition, the car shell is removed to certified shredder companies in the Netherlands and abroad. The Auto & Recycling Foundation pays out premiums for these services to make recycling economically feasible. In this way, 86% of the weight of end-of-life vehicles in the Netherlands is recycled.

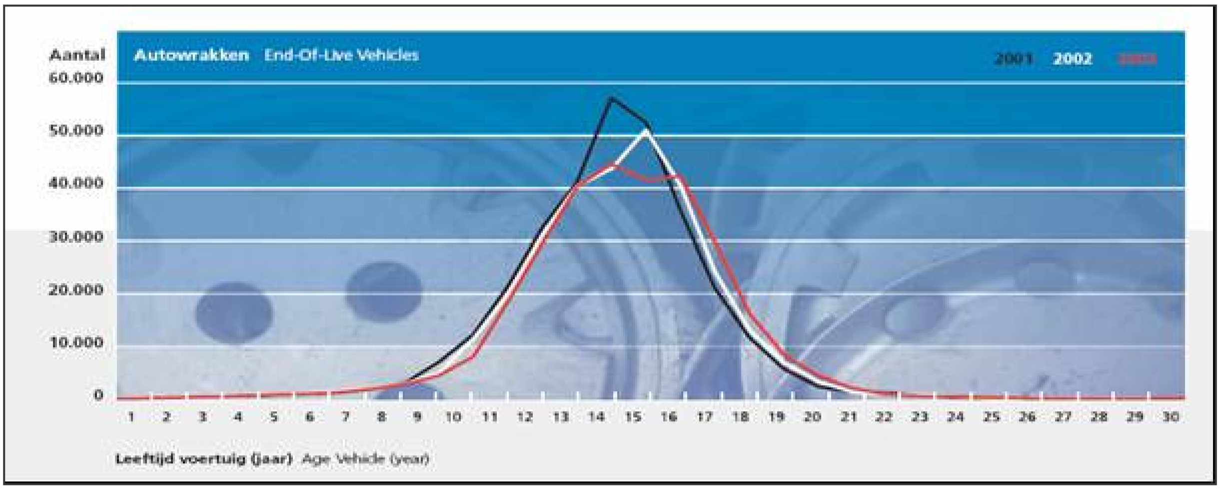

Figure 13: Age of the ELV in the Netherlands. Source [ARN 2004]

Table 5: ARN Materials and standard quantities per ELV [ARN 2004]

MATERIAALSOORT TYPE OF MATERIAL	NORM* STANDARD*	EENHEID UNIT	2003 2003	2002 2002	2001 2001
Accu Battery	13,3	kg	3.390.983	3.384.271	3.534.660
Achter- en knipperlichten Rear lights and indicators	1,4	kg	572.579	27.538	319.837
Banden Tyres	27,9	kg	7.616.913	7.321.248	7.831.005
Binnenbanden Inner tubes	0,1	kg	30.980	56.719	51.260
Brandstoffen (benzine/diesel) Fuel (petrol/diesel)	5,0	kg	212.920	147.217	123.573
Bumpers (PP en PC) Bumpers (PP and PC)	5,6	kg	1.437.180	1.396.530	1.387.800
Glas Glass	25,4	kg	6.100.940	6.001.700	6.050.120
Grilles Grilles	0,5	kg	113.875	62.460	113.900
Koelvloeistof Coolants	3,6	l	898.460	812.400	799.240
Kokoshaar Coconut fibre	0,5	kg	72.760	74.217	87.969
LPG-tank LPG tanks	0,06	stuks l pieces	10.699	6.897	6.783
Olie Oil	4,9	l	1.300.220	1.167.200	1.107.723
Oliefilter Oil filter	0,5	kg	104.740	73.745	—
PUR-schuim PU foam	6,7	kg	1.694.605	1.637.877	1.745.120
Remvloeistof Braking fluid	0,3	kg	92.706	75.657	75.479
Rubberen strips Rubber strips	7,7	kg	1.927.420	1.940.190	1.931.020
Ruitensproeivloeistof Windscreen washer fluid	1,0	kg	238.600	258.780	196.780
Veiligheidsgordels Safety belts	0,35	kg	91.445	94.995	86.320
Wieldoppen Hubcaps	0,7	kg	176.080	174.900	185.300

For 2003 the average weight of all end-of-life vehicles came to 911 kg. Since 2003 it is possible to work with data obtained from vehicle registration numbers of the Centre for Vehicle

The metal content of a complete car is based on literature data and on ARN studies, including a project initiated in 2002 to dismantle many popular models. This gives an average metal content of 75%. This has also been used for the calculation of the figures for the year 2003.

The average amount of ARN materials per car dismantled for ARN in 2003 amounted to 100.1 kg and is calculated on the basis of standard quantities. The residue represents the difference between the average weight of an end-of-life vehicle and the sum of ARN materials and metals.

The figures show that in 2003 ARN achieved the recycling goal of 85%, consisting of a minimum of 80% material recycling and a maximum of 5% thermal processing. ARN did 86%. The average weights of the current ARN materials will further increase in the next few years, because, among other things, plastic components will become larger and heavier.

The new EU Directive includes re-use of components in the recycling targets. Re-use greatly influences recycling data. A re-used component replaces a worn or broken component that itself enters the waste chain. Re-use of components not only extends their life span but also reduces the production of new components and thus the depletion of scarce raw materials.

Table 6: Car recycling in the Netherlands [ARN 2004]

	2003	2003				2002	2002			
			Materiaal-recycling Material-recycling	Thermische-recycling Thermal recycling	Verwijdering Disposal			Materiaal-recycling Material-recycling	Thermische-recycling Thermal-recycling	Verwijdering Disposal
Metalen (aanname)* Metals (assumed)*	683,3 kg	75%	75%			686,9 kg	75%	75%		
ARN-materialen ** ARN materials **										
Materiaalrecycling Material recycling	84.9	9.3%	9.3%			85,0 kg	9,3%	9,3%		
Thermische recycling Thermal recycling	15.6	1.7%		1.7%		15,6 kg	1,7%		1,7%	
restfractie										
Recycling Recycled	**783.8**	**86%**				787,5 kg	86%			
Restfractie Residue	**127.3**	**14%**			**14%**	128,4 kg	14%			14%
Gemiddeld ledig **gewicht wrak** Average unladen weight of end-of-life vehicle	911	100%	84,3%	1,7%	14%	915,9** kg	100%	84,3%	1,7%	14%

* Dit gewicht is op basis van cijfers uit deskresearch I Figures from desk research

** Exclusief brandstoffen en LPG-tanks I Exclusive of fuel(s) and LPG tanks

The number of different types of materials that car dismantling companies have been commissioned by ARN to dismantle has increased every year. ARN has materials dismantled only if high-quality recycling processes are available for the material in question. In addition, research is being carried out on a continuous basis into what materials are present in scrap cars and whether those materials can be processed now or in the future. The moment ARN recognizes a particular material can be recycled, the ARN companies are instructed to dismantle it.

ARN defines the term 'standard quantity' as the average number of kilograms, litres or pieces of material per wreck that a car dismantling company is permitted to submit. Changes in the supply of end-of-life vehicles or improvements in the dismantling techniques can lead to changes in these figures. Every quarter ARN checks to see if adjustments are required.

The car industry set itself the goal of recycling at least 95% of the weight of cars by 2007. The (license) registration system makes it possible to calculate the average weight of an end-of-life vehicle.

The figures show that in 2003 ARN achieved the recycling goal of 85%, consisting of a minimum of 80% material recycling and a maximum of 5% thermal processing. Because of the changing composition of cars it is expected that this percentage will drop in the next few years unless extra materials are dismantled or recuperated after shredding. The average weights of the current ARN materials will further increase in the next few years, because, among other things, plastic components such as bumpers, rear lights, hubcaps and radiator grilles will become larger and heavier. The weight of other components such as batteries, glass, oil, brake fluid and tyres will also increase in the next few years.

5 Quality of scrap wastes

Steel Properties are affected by residual elements, among which: Cu, N, H, S, P Cu, As, Sn. While new technologies like thin slab casting impose stringent restrictions to some residual elements, more generally current regulations and furnace set-ups prescribe residual element percentages for several steel grades that are often lower than what is normally required by the product or the manufacturing process (steel high quality).

In this respect, the need was felt to reconsider the limits of residual elements that are presently applied to the involved steel grades(MILLMANN, 1999).

The production of high quality steel by the integral route induces to reconsider the current Electric Arc Furnace (EAF) and Basic Oxygen Furnace (BOF) technologies to find out a process that utilises scrap and hot metal at best while controlling the residual elements of steel.

5.1 Steel properties

5.1.1 Nitrogen

High nitrogen contents induce strain ageing and lower ductility of low-carbon aluminium-killed (LCAK) flat products.

In the EAF liquid bath, nitrogen arises from:

- scrap containing 30 to 100 ppm of N that is progressively transferred to the bath during melting;
- furnace atmosphere at direct contact with the liquid bath;
- ionised atmosphere around the electric arc where nitrogen is available at atomic or ionic status.

The measures to remove nitrogen from the bath consist in generating foamy slag around the electric arcs, isolating the bath from the atmosphere and promoting the generation of CO starting from the deepest bath layers.

If the EAF charge mix is only composed of scrap, the above measures cannot decrease N contents below 60 ppm.

Lower amounts of N in the BOF charge mix, absence of electric arcs and the cleaning action of CO during O_2 blowing can decrease N contents below 20 ppm.

The content of N that is expected from the hybrid reactor ranges between 20 and 50 ppm, the lower limit being achieved if the charge mix contains 70% of hot metal. The action of the electric arc is smaller because the electric energy input precedes the O_2 cleaning stage and because oil and gas injection into the electric arc area prevents N from developing.

5.1.2 Copper

The effect of copper content in scrap is made worse by the presence of As, Sn and Sb and it is responsible for a phenomenon known as “hot shortness” which is said to endanger the rolling capability of flat products.

Contrary to nitrogen, it cannot be removed from the liquid bath by metallurgical actions and is therefore described as a tramp element just as As, Sn, Ni, etc.

A European regulation defines the minimum content of some tramp elements for some types of scrap, including Cu and Sn (see table below).

Table 7: Structure of the European scrap grading system. Source [Repetto et al 1999]

Scrap category	Designation	% Cu	% Sn	% (Cu+Sn)
Obsolete scrap	E3 E1	<= 0.25 <= 0.40	<= 0.01	<= 0.25
Low residue Scrap	E2 E6 E8	total <= 0.30		
Shredded scrap	E40 E46	<= 0.25 <= 0.50	<= 0.02 <= 0.07	
Turnings	E5H E5M	<= 0.4	<= 0.03	<= 1.00
High residues	EHRB EHRM	<= 0.45 <= 0.40	<= 0.03 <= 0.03	<= 0.35 <= 1.00

6 Alternatives for the shredding process

Metal shredders are a crucial component of the current infrastructure because they can create huge quantities of scrap steel at low expense, making it possible for the industry to achieve high levels of profitability. During the 1960s, before the introduction of the shredder, the automobile recycling industry was rapidly becoming unprofitable. There is therefore a great reliance on shredders as a necessary and valuable technology.

There are therefore not so many lines of thinking in automobile recycling. The first is to maintain the current infrastructure, but tack on a final process which utilizes ASR. The second is to design cars which are made of recycled commodities and can be easily dismantled, reused, and recycled part by part. The first option can be considered as main solution to be used while the infrastructure and technology needed to implement the second are developed. However, even the *short term* solutions for recycling ASR require more research and development before they will be able to handle the huge amount of fluff produced every year.

Several options have been proposed for dealing with fluff: alternative daily cover in landfills, fillers in composite materials, and feedstock recovery via pyrolysis or other recycling technologies as detailed in other work packages. Hypothetically, incineration is also an option, but it is not considered as a means to deal with fluff because it doesn't burn efficiently. A variety of processes are being used to prevent the creation of fluff in the first place. Although the specific reprocessing technologies differ, Annex I of the ELV directive requires for all some degree of dismantling before the steel hulk is crushed or shredded for scrap. The more comprehensive a dismantling process, the less fluff and the higher the costs ultimately created.

Another important factor in the recycling equation is the inherent recyclability of the automobile. This term refers to the potential of a car to be recycled using processes which are technically, economically, and environmentally feasible. Nearly all car manufacturers are experimenting with how to make cars more recyclable. However, this is a very slow process. It takes years for design changes to move from drawing boards to prototypes, and from prototypes to models for sale. After new designs are marketed, it still takes the lifetime of the car (currently 10-15 years) before they can be appreciated by the recycler.

An optimized car recycling could work like shown in the next figure:

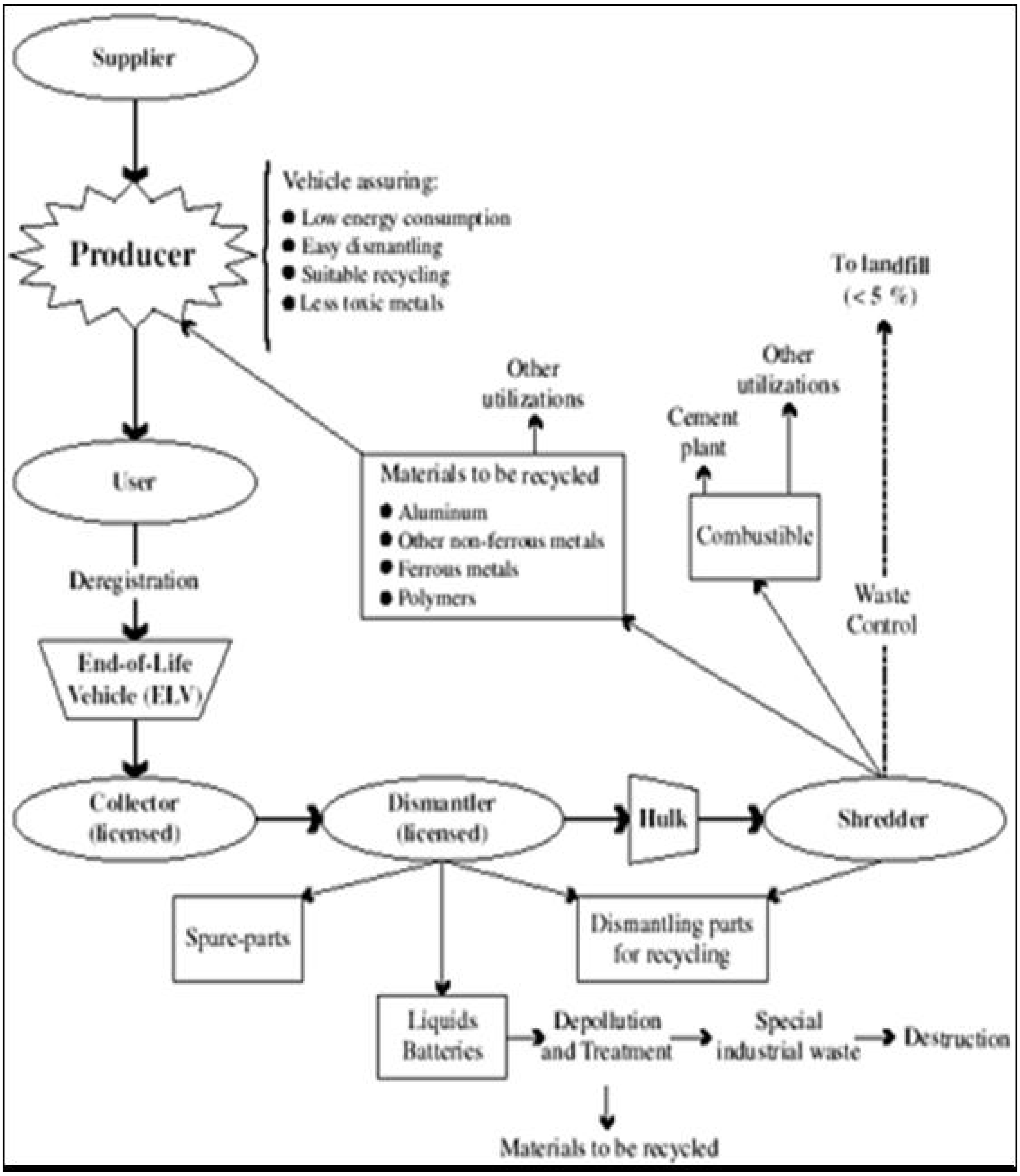

Figure 14: alternative car recycling system – also including the shredder process. Source: [Kanari et al. 2004]

Shredder facilities' primary interest is in metal recovery. Their profits come from the metals recovered (primarily ferrous lead, aluminium, and brass). Shredder facilities have advanced processes to maximize their metal recovery from end-of-life vehicles (ELVs). The use of high power magnets, secondary separation, and eddy current systems allow them to separate 95% of the non-ferrous and ferrous metals from shredded material (75% of the total vehicle weight). However, a significant amount of metal remains in ASR. The limiting factor in recovering these metals is that they are intimately bound to various plastics and coatings. If these plastics and coatings are removed, the metals can be reclaimed and refined for profit.

The new movement for improved automobile recycling has its origins in European legislation. These laws were also designed to avoid a decline in the economic feasibility of fluff generation and disposal.

While national legislation is one way in which change can be mandated, a variety of additional solutions also exist. Regional governments and citizen's organizations can provide an environment which is favourable to progressive recycling systems, thereby attracting them to the area and fostering their development. However, any Design-for-Disassembly approach is questioned if there are quite different requirements in the different regions/member states as the design solutions of a global product cannot be regionalized in an efficient way. Also, the necessary volumes (economies-of-scale) for recycled materials will not be established if the national implementations of the ELV directive are not fully aligned.

Furthermore the requirements as set in the EU ELV directive and the solutions found in practice should be evaluated regarding their real total environmental improvement. The requirements should be evaluated from a life cycle perspective as suggested in WP7 - looking for the most effective and efficient ways for environmental improvements rather than being fixed at general quotas.

7 Results from the shredding tests

7.1 Transport scenarios

Scenario 1

Scenario 1 its the current situation. As many cars as possible are loaded into open container trucks by a crane. On average it is possible to load 12 cars per truck. The loading ist very fast – about half an hour. In this scenario the roofs of the cars are pressed down and the cars are partly damaged.

Advantage: cheap transport because of fast and space efficient loading

Disadvantage: Dismantling of components in the interior is hardly possible

Scenario 2

Scenario 2 is a fictitious scenario in which cars are loaded into open container trucks by a crane avoiding any damage to the cars as good as possible. Cars are carefully put on each other so that the roofs are not pressed flat. On average it should be possible to load 8 cars. The loading should also be very fast like in scenario 1.

Advantage: cheaper transport as in scenario 3, dismantling should be possible also from the interior in most cases

Disadvantage: more expensive transport as in scenario 1

Scenario 3

Scenario 3 is also a fictitious scenario in which cars are loaded on special trucks that are normally used for new cars. For a not too complicated loading the cars should still be functioning. At least tires are needed to pull or push the cars onto the truck. If the cars are not functioning you need 4 persons to load the truck. 8 cars per truck could be loaded.

Advantage: the cars should arrive in the same constitution as they are collected

Disadvantage: Very expensive loading, loading is sometimes hardly possible

Table 8: comparison of the costs of the different scenarios

	number of ELV	average distance/ transport [km]	costs per km	costs for distance	person hours for loading	costs per person hour	costs for loading	costs for 1 transport	cost per ELV
scenario 1	12	150	€ 1.00	€ 150,00	0.5	€ 30	€ 15	€ 165.00	€ 13.75
scenario 2	8	150	€ 1.00	€ 150,00	0.5	€ 30	€ 15	€ 165.00	€ 20.63
scenario 3	8	150	€ 1.00	€ 150,00	15	€ 30	€ 450	€ 600.00	€ 75.00

(Reduced number of ELV per truck does not only increase cost per ELV but also the specific environmental impact of transport per ELV because of fuel consumption and driving emissions of the truck.)

7.2 ELV-Inputs for the shredding tests

The ELV input for the shredding tests should be representative for a typical mixture that arrives at the shredding plants - as described in chapter 2.2.1.

7.2.1 Cars for the first shredding test in Amstetten

Table 9: Overview of the cars for the first shredding test in Amstetten

Overview				
KIA GTX 1992	Opel Omega 1991	Mitsubishi Lancer D 1990	Citroen BX D 1989	VW Transporter 1990
Toyota Corolla 1992	Seat Ibiza 1990	Fiat Uno 1986	VW Golf 2 D 1989	Ford Sierra 1989
Ford Escort 1987	Mazda 323 1989	Opel Corsa 1986	Audi 80 1986	Opel Astra 1995
Alfa 33 1991	Mazda 626 1992	Suzuki Swift 1993	VW Golf 2 1990	Peugeot 405 1992
VW Golf 2 1987	VW Golf 2 1988	Audi 80 1982	VW Golf 2 1985	Renault 4 1981
Renault 5 1990	Nissan Sunny 1989	BMW 316 1986	VW Jetta 1990	Opel Vectra 1994

The last two cars (VW Jetta 1990 and Opel Vectra 1994) were taken as substitutes for the Mercedes samples, because Mercedes cars were not available in the required form.

7.2.2 Cars for the second shredding test in Amstetten

Table 10: Overview of the cars for the second shredding test in Amstetten

Overview				
Ford Sierra 1990	Audi 80 1987	Peugeot 205 1989	Chrysler Voyager 1992	Opel Ascona 1990
Honda Civic 1987	Mazda 323 1994	Opel Vectra 1992	Nissan 100 NX 1993	Volvo 740 1988
VW Polo 1983	Mazda 323 1994	Audi 100 1988	VW Golf 1986	Opel Kadett 1985
Mitsubishi Lancer 1989	Honda Civic 1987	VW Golf 1982	Fiat Tipo 1993	BMW 320 1990
Renault 11 1982	Renault 21 1987	Ford Sierra 1990	VW Vento 1998	Daihatsu Applause 1994
VW Passat 1985	VW Golf 2 1987	Mitsubishi Galant 1996	Toyota Celica 1986	Volvo 740 1987

The Mitsubishi Galant 1996 and the Volvo 740 1987 were taken as substitutes for the Mercedes cars, which were not available in the required form.

7.2.3 Cars for the first shredding test in Budapest

Table 11: Overview of the cars for the first shredding test in Budapest

Overview				
VW Passat 1978	Wartburg 1981	Opel Kadett 1982	Skoda 105 1982	Fiat (Poland) 1989
Opel Rekord 1977	Lada 2105 1983	Honda Akkord 1978	Volkswagen Si-rocce 1980	Talbot 1981
Zastawa 1985	Datsun 1983	Trabant 6015 1986	Barkas 1982	Ford Fiesta 1987
Wartburg 1980	VW Passat 1982	Citroen 1980	Opel Rekord 1981	Renault 1985
Renault 1987	Toyota 1980	Toyota 1981	Mazda 626 1983	Citroen 1985
Mazda 626 1985	Fiat 127 1984	Ford Sierra 1985	Opel Ascona 1987	Mercedes 1980
Lada Samara 1987	Honda Civic 1990	Lada 1200 1978	Wartburg 353 1980	Trabant 1984
Oltcit 1984	Wartburg 1980	Mazda 323 1985	Lada 1200 1980	Skoda 105 1983

7.2.4 Cars for the second shredding test in Budapest

Table 12: Overview of the cars for the second shredding test in Budapest

Overview				
Trabant 1982	Zastava 1985	Wartburg 1984	Skoda 1983	Skoda 1986
Wartburg 1982	Skoda 1983	Trabant 1981	Austin 1986	Skoda 1985
Wartburg 1981	Volvo 1981	Fiat (Poland) 1990	Skoda 1989	Fiat 1981
Opel 1984	Fiat (Poland) 1982	Wartburg 1983	Fiat (Poland) 1985	Trabant 1983
Dacia 1981	Wartburg 1983	Volvo 1985	Wartburg 1986	Wartburg 1985
Lada 1989	Wartburg 1984	Skoda 1982	Wartburg 1981	Zastava 1986

7.3 Pre-treatment for the shredder tests

The collected cars in Amstetten were pre-treated and depolluted. The following substances and parts were separated:

- oil
- fuels
- battery
- catalytic converter
- rubber from tyres
- rims
- lead from tyres
- valves from tyres
- brake liquid
- cooling liquid
- window cleaning liquid

The collected cars in Budapest were also depolluted as far as it was required (many of the cars especially from the first test arrived already completely dismantled).

7.3.1 Pre-treatment first shredding trial in Amstetten

Table 13: Pre-treatment fractions of the first shredding test in Amstetten (30 cars)

Fraction	Weight	Percentage of total weight
Oil	70.45 kg	0.25 %
Petrol	185.60 kg	0.65 %
Diesel	61.9 kg	0.22 %
Battery	219.55 kg	0.77 %
Catalytic converter	61.05 kg	0.22 %
Rubber from tyres	847.20 kg	2.99 %
Rims	961.50 kg	3.39 %
Valves from tyres	1.67 kg	0.01 %
Lead from tyres	8.95 kg	0.03 %
Brake liquid	3.40 kg	0.01 %
Cooling liquid	34.28 kg	0.12 %
Window cleaning liquid	12.05 kg	0.04 %
Summary	**2467.60 kg**	**8.70 %**
Loss	**72.41 kg**	**0.26 %**

Table 14. Pre-treatment balance for the first shredding test in Amstetten (per car)

Manufacturer	Type	Missing components	Before pre-treatment [kg]	After pre-treatment [kg]
VW	Transporter D	Engine, transmission	1130	1030
VW	Golf 2 D	Battery	860	800
VW	Golf 2	Battery, alternator	800	720
VW	Golf 2	Battery, alternator, starter motor	900	820
VW	Golf 2	-	890	800
VW	Golf 2	Battery	920	830
Vw	Jetta	-	960	880
Opel	Omega	-	1450	1310
Opel	Corsa	Battery	690	630
Opel	Astra	Battery	1020	920
Opel	Vectra	Tyres, alternator	990	970
Ford	Sierra	-	1210	1040
Ford	Escort	-	940	790
Renault	5	-	780	700
Renault	4	Battery	660	610
Audi	80	Battery, alternator, cooler	880	810
Audi	80	Battery	870	790
Mazda	323	Battery	890	820
Mazda	626	Tyres, cooler, alternator	1030	980
Toyota	Corolla	Battery	890	820
Peugeot	405	Battery	1060	970
BMW	316	-	1020	940
Fiat	Uno	Battery	710	640
Nissan	Sunny	-	1050	960
Alfa	33	Tyres	860	820
Citroen	BX D	-	1000	900
Mitsubishi	Lancer D	-	1080	980
KIA	GTX	-	1040	940
Seat	Ibiza	-	910	820
Suzuki	Swift	-	870	780
overall			**28 360**	**25 820**

7.3.2 Pre-treatment second shredding trial in Amstetten

Table 15: Pre-treatment fractions for the second shredding test in Amstetten (30 cars)

Fraction	Weight	Percentage of total weight
Oil	53.05 kg	0.19 %
Petrol	183.35 kg	0.64 %
Diesel	49.65 kg	0.17 %
Battery	176.65 kg	0.62 %
Catalytic converter	52.50 kg	0.18 %
Rubber from tyres	695.20 kg	2.43 %
Rims	788.60 kg	2.76 %
Valves from tyres	1.29 kg	0.00 %
Lead from tyres	7.14 kg	0.02 %
Brake liquid	3.20 kg	0.01 %
Cooling liquid	38.25 kg	0.13 %
Window cleaning liquid	9.90 kg	0.03 %
overall	**2058.78 kg**	**7.20 %**
Loss	**81.23 kg**	**0.28 %**

Table 16: Pre-treatment balance for the second shredding test in Amstetten (per car)

Manufacturer	Type	Missing components	Before pre-treatment [kg]	After pre-treatment [kg]
Ford	Sierra	One tyre	1120	1030
Audi	80	Alternator, one tyre	890	810
Peugeot	205	Cooler, one tyre	790	740
Chrysler	Voyager	-	1580	1440
Opel	Ascona	Cooler	860	760
Honda	Civic	-	820	740
Mazda	323	-	970	930
Opel	Vectra	Engine, cooler	800	730
Nissan	100 NX	One tyre	990	920
Volvo	740	One tyre	1500	1340
VW	Polo	-	690	620
Mazda	323	Engine parts, alternator, starter motor	1110	1020

Manufacturer	Type	Missing components	Before pre-treatment [kg]	After pre-treatment [kg]
Audi	100	-	1310	1200
VW	Golf	-	960	870
Opel	Kadett	-	990	890
Mitsubishi	Lancer	-	1160	1070
Honda	Civic	-	820	740
VW	Golf	Doors	690	610
Fiat	Tipo	Cooler, one tyre, cat.	900	830
BMW	320	One tyre	1090	990
Renault	11 TC	-	750	700
Renault	21 TS	Engine, cooler, one tyre,	890	820
Ford	Sierra	One tyre	1090	1020
VW	Vento	-	1030	980
Daihatsu	Applause	Cat.	950	910
VW	Passat	Cooler	890	810
VW	Golf 2	Tyres, battery	780	770
Mitsubishi	Galant	Tyres, battery	810	810
Toyota	Celica	Engine, cooler, tyres	580	580
Volvo	740	Engine, cooler, tyres	790	790
overall			**28 610**	**26 470**

7.3.3 Pre-treatment first shredding trial in Budapest

The pre-treatment of the cars was not documented this time because the cars were not in comparable conditions like in Amstetten when they arrived at the facility. The weight of the cars after pre-treatment (shredder input) was 36960 kg.

7.3.4 Pre-treatment second shredding trial in Budapest

Table 17: Pre-treatment balance for the second shredding test in Amstetten (per car)

Manufacturer	Missing components	Before pre-treatment [kg]	After pre-treatment [kg]
Trabant		600	520
Zastava		840	700
Wartburg		920	820
Skoda		860	740

Manufacturer	Missing components	Before pre-treatment [kg]	After pre-treatment [kg]
Skoda		850	730
Wartburg		930	830
Skoda		870	750
Trabant		600	520
Austin		660	570
Skoda		850	730
Wartburg		910	830
Volvo		1230	1160
Fiat (Poland)		560	490
Skoda		850	730
Fiat		670	590
Opel		1490	1380
Fiat (Poland)		560	490
Wartburg		920	830
Fiat (Poland)		550	480
Trabant		600	520
Dacia		960	870
Wartburg		890	830
Volvo		1280	1190
Wartburg		910	830
Wartburg		910	830
Lada		940	870
Wartburg		920	870
Skoda		840	770
Wartbrug		940	850
Zastava		830	720
Summary		**25740**	**23040**

7.4 Assessment of EES content in the cars

7.4.1 Assessment of EES for the first shredding test Amstetten

Table 18: Assessment of EES for the first shredding test in Amstetten

Component	Total Weight in all cars	Percentage % whole car/shredder input
Starter motor	111.5 kg	0.39/0.43
Alternator	100.0 kg	0.35/0.39
Wire harness	219.0 kg	0.77/0.85
Lambda control sensor	1.4 kg	0.004/0.005
Passive junction box	20.6 kg	0.07/0.08
ECU	7 kg	0.02/0.03
overall	**459.5 kg**	**1.62/1.78**

7.4.2 Assessment of EES of the second shredding test Amstetten

Table 19: Assessment of EES for second shredding test in Amstetten

Component	Total Weight in all cars	Percentage % whole car/shredder input
Starter motor	108.0 kg	0.38/0.41
Alternator	106.0 kg	0.37/0.40
Wire harness	227.0 kg	0.79/0.92
Lambda control sensor	1.1 kg	0.004/0.004
Passive junction box	17.5 kg	0.06/0.07
ECU	7.5 kg	0.03/0.03
overall	**467.1 kg**	**1.63/1.76**

7.4.3 Assessment of EES of the first shredding test Budapest

Table 20: Assessment of EES for the first shredding test in Budapest

Component	Total Weight in all cars	Percentage % shredder input
Starter motor	142.5 kg	0.39
Alternator	153.9 kg	0.42
Wire harness	93.9 kg	0.25

Lambda control sensor	0.2 kg	0.0005
Passive junction box	6.3 kg	0.017
ECU	1.0 kg	0.0027
overall	**397.8 kg**	**1.076**

7.4.4 Assessment of EES of the second shredding test Budapest

Table 21: Assessment of EES for the second shredding test in Budapest

Component	Total Weight in all cars	Percentage % shredder input
Starter motor	96.0 kg	0.42 %
Alternator	101.0 kg	0.44 %
Wire harness	135.0 kg	0.58 %
Lambda control sensor	0.4 kg	< 0.01 %
Passive junction box	4.2 kg	0.02 %
ECU	1.0 kg	< 0.01 %
overall	**337.6 kg**	**1.47 %**

7.5 Input-Output-Balance:

The weights from following tables are weighed with different scales:

- Total input - platform scale (sum of single weights of each complete car)
- Output depollution and dismantling – small industry scale – max 50 kg (sum of single weights of depolluted fractions from each car)
- Shredder-input (depolluted cars – platform scale (sum of single weights of each depolluted car)
- Output steel fraction – conveyor belt scale (not very exact)
- Output Cu/Fe compounds – industry scale – max 500 kg
- Output rubber and textiles handpicked from steel fraction – industry scale – max 500 kg
- Output non-ferrous heavy fraction – platform scale
- Output non-magnetic light fraction – platform scale
- Output magnetic light fraction – platform scale

There are some losses of material that become dust and remain in the filters. We cannot define the quantity of this loss very exact because some water is added to the shredder to reduce the dust and the conveyor belt scale for the steel fraction is not very exact – +/- 10 %.

The loss is not very high because the overall quantity of dust in the filters is quite low over a shredder input quantity of 100,000 tons over a year. So we took the difference of the sum of the shredder output weights from the platform scale and the industry scale to the shredder-input weight as weight of the steel fraction. The weight from the conveyor belt scale was taken as reference for comparison.

7.5.1 I-O-Balance – first trial in Amstetten

Table 22. I-O-Balance for the first shredding test in Amstetten

Fraction	Weight	abs. %	Shredder-Input %
Total input: 30 cars	**28360 kg**		
output depollution and dismantling	2540 kg	8.96%	
Shredder-Input (depolluted cars)	25820 kg	91.04%	100 %
output steel fraction	18780 kg	66.22%	72.73%
output Cu/Fe compounds (handpicked from steel fraction)	50 kg	0.18%	0.19%
output rubber and textiles (handpicked from steel fraction)	60 kg	0.21%	0.23%
output non-ferrous heavy fraction	2420 kg	8.53%	9.37%
output magnetic light fraction	2110 kg	7.44%	8.17%
output non-magnetic light fraction	2400 kg	8.46%	9.30%

7.5.2 I-O-Balance – second trial in Amstetten

Table 23: I-O-Balance for the second shredding test in Amstetten

Fraction	Weight	abs.%	Shredder-Input %
Input: 30 cars	**28610 kg**		
depollution and dismantling	2140 kg	7.48%	
Shredder-Input (depolluted cars)	26470 kg	92.52%	100 %
steel fraction	18770 kg	65.61%	70.91%
Cu/Fe compounds handpicked from steel fraction	50 kg	0.17%	0.19%
rubber and textiles handpicked from steel fraction	160 kg	0.56%	0.60%
non-ferrous heavy fraction	3570 kg	12.48%	13.48%
magnetic light fraction	1500 kg	5.24%	5.67 %
non-magnetic light fraction	2420 kg	8.46%	9.14 %

7.5.3 I-O-Balance – first trial in Budapest

Table 24: I-O-balance for the first shredding test in Budapest

Fraction	Weight		Shredder-Input %
Shredder-Input (depolluted cars)	36960	kg	100%
Output steel fraction	24490	kg	66.26%
Output Cu/Fe compounds handpicked from steel fraction	140	kg	0.38%
Output: rubber and textiles handpicked from steel fraction	90	kg	0.24%
Output: non-ferrous heavy fraction	5300	kg	14.34%
Output: light fraction	6940	kg	18.78%

7.5.4 I-O-Balance – second trial in Budapest

Table 25: I-O-balance for the second shredding test in Budapest

Fraction	Weight		Shredder-Input %
Shredder-Input (depolluted cars)	23040	kg	100%
Output steel fraction	17000	kg	73.78%
Output Cu/Fe compounds handpicked from steel fraction	80	kg	0.35%
Output: rubber and textiles handpicked from steel fraction	100	kg	0.43%
Output: non-ferrous heavy fraction	1740	kg	7.55%
Output: light fraction	4120	kg	17.88%

7.6 Analysis of obtained output fractions

To have an idea about the qualities of the different obtained fractions handpicking analysis were carried out. The non-ferrous heavy fraction from Amstetten ran through a post-shredder-treatment and was analysed afterwards.

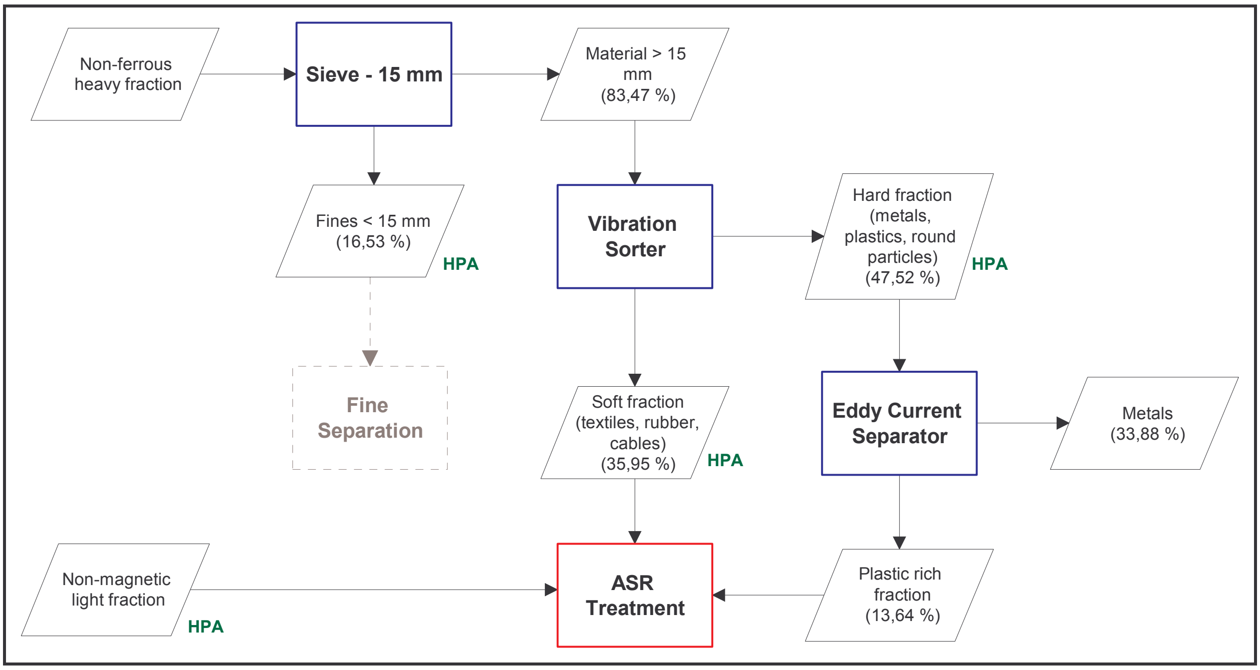

Figure 15: Overview over the post-shredder treatment

The theoretical weight in the tables are calculated values for the whole quantity of the fraction based on the percentage of the handpicking analysis.

7.6.1 Fractions first trial Amstetten

Table 26: Steel fraction (710 kg sample)

Fraction	theor. Weight	Abs. %	Shredder-Input %	steel fraction %
cables, wires	39 kg	0.14%	0.15%	0.21%
steel	18741 kg	66.08%	72.58%	99.79%

Table 27: Magnetic light fraction (42 kg sample)

Fraction	theor. Weight	Abs. %	Shredder-Input %	magn. light fraction %
cables, wires	11 kg	0.04%	0.04%	0.52%
dirt, dust	2099 kg	7.40%	8.13%	99.48%

Table 28: Non-magnetic light fraction (31 kg sample)

Fraction	theor. Weight	Abs. %	Shredder-Input %	light fraction %
Metals	8 kg	0.03 %	0.03 %	0.33 %
Cables/wires	35 kg	0.12 %	0.14 %	1.46 %
Plastics	330 kg	1.16 %	1.28 %	13.75 %
Rubbers	29 kg	0.10 %	0.11 %	1.21 %
Foam	134 kg	0.47 %	0.52 %	5.58 %
Mixed fluff	1864 kg	6.57 %	7.22 %	77.67 %

Mixed fluff is a mixture of fines, textiles, plastics, rubber and small foam pieces that can’t be separated efficient by hand.

Table 29: Hard fraction of the non-ferrous heavy fraction (46 kg sample)

Fraction	theor. Weight	Abs. %	Shredder-Input %	heavy fraction %	hard fraction %
Metals	732 kg	2.58%	2.84%	30.25%	63.65%
Cables, wires	62 kg	0.22%	0.24%	2.57%	5.42%
plastics	196 kg	0.69%	0.76%	8.11%	17.07%
Foam	22 kg	0.08%	0.09%	0.92%	1.94%
rubbers	91 kg	0.32%	0.35%	3.78%	7.95%
compounds with metals	14 kg	0.05%	0.05%	0.58%	1.22%
PCBs	9 kg	0.03%	0.03%	0.37%	0.79%
Others	23 kg	0.08%	0.09%	0.94%	1.97%

Table 30: Soft fraction of the non-ferrous haevy fraction (24 kg sample)

Fraction	theor. Weight	Abs. %	Shredder-Input %	heavy fraction %	soft frac-tion %
cables, wires	82 kg	0.29%	0.32%	3.38%	9.40%
Fluff	337 kg	1.19%	1.30%	13.92%	38.72%
plastics	139 kg	0.49%	0.54%	5.74%	15.97%
rubbers	287 kg	1.01%	1.11%	11.86%	32.98%
compounds with metals	5 kg	0.02%	0.02%	0.21%	0.58%
metals	21 kg	0.07%	0.08%	0.85%	2.36%

Table 31: Fine fraction of the non-ferrous heavy fraction (6 kg sample)

Fraction	theor. Weight	abs. %	Shredder-Input %	heavy fraction %	soft fraction %
Metals	107 kg	0.38 %	0.41 %	4.41 %	26.68 %
Cables, wires	34 kg	0.12 %	0.13 %	1.39 %	8.41 %
Rest	260 kg	0.92 %	1.01 %	10.73 %	64.91 %

7.6.2 Fractions second trial Amstetten

Table 32: Steel fraction (237 kg sample)

Fraction	theor. Weight	abs. %	Shredder-Input %	steel fraction %
cables, wires	47 kg	0.16%	0.18%	0.25%
steel	18723 kg	65.44%	70.73%	99.75%

Table 33: Magnetic light fraction (32 kg sample)

Fraction	theor. Weight	abs. %	Shredder-Input %	magn. light fraction %
Cables, wires	16 kg	0.05%	0.06%	0.76%
Dirt, dust	1484 kg	5.19%	5.61%	98.93%

Table 34: Non-magnetic light fraction (ASR treatment, WP5 data)

Fraction	Theor. Weight	abs. %	Shredder-Input %	light fraction %
Metals	25 kg	0.08%	0.09%	1.03%
Cables/wires	10 kg	0.03%	0.04%	0.41%
Plastics	532 kg	1.86%	2.01%	21.99%
Rubbers	407 kg	1.42%	1.54%	16.82%
Mixed fluff	1446 kg	5.05%	5.46%	59.75%

Table 35: Non-ferrous heavy fraction (ASR treatment, WP5 data)

Fraction	Theor. Weight	abs. %	Shredder-Input %	Heavy fraction %
Metals	1135 kg	3.97%	4.29%	31.79%
Cables/wires	180 kg	0.63%	0.68%	5.04%
Plastics	960 kg	3.36%	3.63%	26.89%
Rubbers	395 kg	1.38%	1.49%	11.06%
Mixed fluff	900 kg	3.15%	3.40%	25.21%

7.6.3 Fractions first trial Budapest

Table 36: Steel fraction (660 kg sample)

Fraction	Theor. Weight	Shredder-Input %	steel fraction %
Cables, wires	110 kg	0.30%	0.45%
Steel	24380 kg	65.96%	99.55%

Table 37: Light fraction (51 kg sample)

Fraction	theor. Weight	Shredder-Input %	light fraction %
Cables, wires	42 kg	0.11%	0.61%
Fluff	993 kg	2.69%	14.31%
Rubber	1217 kg	3.29%	17.54%
Plastics	548 kg	1.48%	7.90%
Fines	4083 kg	11.05%	58.83%
Metals	57 kg	0.15%	0.82%

Table 38: Non-ferrous heavy fraction (67 kg sample)

Fraction	theor. Weight	Shredder-Input %	Heavy fraction %
Metals	1982 kg	5.36%	37.40%
Cables/wires	54 kg	0.15%	1.02%
Plastics	1038 kg	2.81%	19.58%
Rubbers	1326 kg	3.59%	25.02%
Fines	572 kg	1.55%	10.79%
Others	328 kg	0.89%	6.19%

7.6.4 Fractions second trial Budapest

Table 39: Steel fraction (480 kg sample)

Fraction	Theor. Weight	Shredder-Input %	steel fraction %
Cables, wires	54 kg	0.23%	0.32%
Steel	16946 kg	73.55 %	99.68%

Table 40: Light fraction (48 kg sample)

Fraction	theor. Weight	Shredder-Input %	light fraction %
Cables, wires	25 kg	0.11 %	0.61%
Fluff	590 kg	2.56 %	14.31%
Rubber	723 kg	3.14 %	17.54%
Plastics	325 kg	1.41 %	7.90%
Fines	2424 kg	10.52	58.83%
Metals	33 kg	0.14	0.82%

Table 41: Non-ferrous heavy fraction (67 kg sample)

Fraction	theor. Weight	Shredder-Input %	Heavy fraction %
Metals	651 kg	2.83 %	37.40%
Cables/wires	18 kg	0.08 %	1.02%
Plastics	341 kg	1.48 %	19.58%
Rubbers	435 kg	1.89 %	25.02%
Fines	188 kg	0.82 %	10.79%
Others	107 kg	0.46 %	6.19%

8 Analysis and discussion of the results

8.1 Analysis pre-treatment output materials: (without dismantling EES)

Negative values in the following table mean costs for the dismantler, positive mean revenues. The values are average values from experiences of Mueller-Guttenbrunn.

Table 42: Analysis of output materials

Fraction	Average quantity/car	What happens	Value/kg	Value per car
Oil	2.09 kg	Disposal	- € 0.04/kg	- €0.08
Petrol	6.12 kg	Reuse: disposal 90:10	- € 0.026/kg	- € 0.16
Diesel	1.85 kg	Reuse: disposal 70:30	- € 0.012/kg	- € 0.02
Battery	6.60 kg	Recycling	+/- € 0.00/kg	+/- € 0.00
Catalytic converter	0.95 kg	Recycling	+ € 5.50/kg	+ € 5.23
Rubber from tyres	25.71 kg	Thermal recycling	- € 0.075/kg	- € 1.93
Rims from tyres	29.17 kg	Recycling	+ € 0.10/kg	+ € 2.92
Valves from tyres	0.05 kg	Recycling	+ € 0.85/kg	+ € 0.04
Lead from tyres	0.27 kg	Recycling	+ € 0.25/kg	+ € 0.07
Brake liquid	0.11 kg	Disposal	- € 0.04/kg	- € 0.004
Cooling liquid	1.21 kg	Reuse/disposal 80:20	- € 0.03/kg	- € 0.04
Window cleaning liquid	0.37 kg	Disposal	- € 0.12/kg	- € 0.04
Loss	2.56 kg	Shredder	+/- € 0.00/kg	+/- € 0.00
			overall	**+ € 5.99**

8.2 Costs of the pre-treatment process

Table 43: Costs of pre-treatment process

Costs	Time/car	Costs/hour	Costs/car
Person hours	0.333 hour	€ 30	€ 10.00
Depollution plant	0.166 hour	€ 15	€ 2.49
Excavator	0.033 hour	€ 65	€ 2.15
		overall	**€ 14.64**

All cost are based on data from Mueller-Guttenbrunn.

8.3 Cost-revenue balance for pre-treatment

Table 44: Costs to revenue balance

Value obtained fractions/car	€ 5.99
costs pre-treatment process/car	€ 14.64
Financial result pre-treatment/car	-€ 8.65

8.4 Costs calculation shredding process

Table 45: Costs to revenues balance of the shredding process

Fraction	**Average/car Amstetten**	**Value/ton Average**	**Value/car**	**1st trial Budapest**	**Value/ton average**	**Value/car**
steel fraction	681.93 kg	€ 130	€ 88.65	592.71kg	€ 130	€ 77.05
Cu/Fe compounds handpicked from steel fraction	1.80 kg	€ 350	€ 0.63	3.14 kg	€ 350	€ 1.10
rubber and textiles handpicked from steel fraction	3.99 kg	- € 150	- € 0.60	2.71 kg	- € 150	- € 0.41
non-ferrous heavy fraction	108.43 kg	+ € 230	€ 24.94	100.57 kg	+ € 230	€ 23.13
magnetic light fraction	65.71 kg	- € 150	- € 9.86	158 kg	- € 150	- € 23.70
non-magnetic light fraction	87.54 kg	- € 115	- € 10.07			
		overall	**€ 93.69**		**overall**	**€ 77.17**

The percentages in the upper table are related to the shredder input quantities. The values are average values from experiences of Mueller-Guttenbrunn.

8.5 Financial result shredding process:

Table 46: Financial result of the shredding process

	Amstetten	Budapest
Value of obtained fractions/car	€ 93.69	€ 84.94
Costs shredding process/car	€ 52.66	€ 48.70
Result shredding process	**€ 41.03**	**€ 36.24**

Table 47: Financial result of the shredding process including transport scenario 1

	Amstetten
Value of obtained fractions/car	€ 93.69
Costs shredding process/car	€ 52.66
Costs for transport scenario 1	€ 13.75
Result shredding process	**€ 27.28**

Table 48: Financial result of the shredding process including transport scenario 2

	Amstetten
Value of obtained fractions/car	€ 93.69
Costs shredding process/car	€ 52.66
Costs for transport scenario 2	€ 20.63
Result shredding process	**€ 23.40**

Table 49: Financial result of the shredding process including transport scenario 3

	Amstetten
Value of obtained fractions/car	€ 93.69
Costs shredding process/car	€ 52.66
Costs for transport scenario 3	€ 75.00
Result shredding process	**€ -33.97**

8.6 Quality aspects of the shredding trials

8.6.1 Copper in steel fraction

The results from Amstetten – 0.21 % cables and 0.25 % cables, which means about 0.10 % - 0.15 % copper fulfil the requirement of copper below 0.25 % very safe. In milestone M9, Table 11 we had a data from literature, which were different from the internal requirements. The result from Budapest – 0.45 % cables, which means about 0.20 % - 0.25 % copper is closer to this value.

There are two possibilities to prevent a too high copper content in the steel fraction. On the one hand it is possible to separate the copper from the steel fraction by hand-picking like in practice. On the other side it would be possible to dismantle copper containing components before the shredder

Table 50: Copper in steel fraction

	Shredding trials Amstetten **Copper hand-picked**	**Shredding trial Budapest** **Copper hand-picked**	**Theoretical scenario (based on WP 3 data)** **Copper (EES) dismantled**
Number of cars	30	40	1
Dismantled EES	no dismantling	no dismantling	Starter motor, alternator, engine wire harness
Copper in steel fraction	0.15 %	0.23 %	< 0.10 %
Quality of steel fraction	Ok	Ok	Ok
Person hours spent for copper (EES) separation	1.5	2	0.525
Person hours for copper (EES) separation of 100 cars	(1.5/30*100=) 5	(2/40*100=) 5	(0.525*100=) 52.5

After specifications the copper content has to be smaller than 0.25 %. The quality is better if the copper content is only 0.05 % than if it is 0.25 % but this doesn't effect the price because the material is used as if it had 0.25 % (mixed with new material).

So the 10 times more person hours spent for separating the copper before the shredder would not be worth it in this case. Even if the copper content gets higher in newer cars, the handpicking of copper from steel fraction will be more efficient than to dismantle the copper containing parts before, because also the dismantling will be more effort. Probably it will need more people for hand-picking but also for the scenario with dismantling EES.

8.6.2 Cables in rest fractions

Copper and u and Cl – both contents of cables – are two quality influencing factors for energy recovery of waste fractions. But as the following tables show, the copper content is not the only content that is too high for blast furnace or cement industry.

The actual values are based on detailed analysis at Mueller-Guttenbrunn.

Table 51: Cables in rest fractions

	Blast furnace (threshold value)	**Cement industry (threshold value)**	**Fluidized bed furnace (threshold value)**	**Stoker-fired furnace (threshold value)**	**Magnetic light fraction**	**Residues non-fe light fraction**	**Residues non-fe heavy fraction**
Pb [mg/kg]		200			5,150	3,000	1,100
Co [mg/kg]		20			390	400	65
Cu [mg/kg]	1,000	150			8,750	4,230	9,200
Zn [mg/kg]	1,000				27,500	6,200	5,500
Cl [%]	1.5	2.0	3.0	3.0	0.71	1.69	2.2

There is no possibility to improve the quality of waste fractions only by controlling the copper (cable) content of the steel.

9 Conclusions and recommendations

9.1 Transport Aspects

Dismantling EES before shredding is only possible if the cars arrive in a good constitution at the shredding plants. This can be only ensured if cars are transported like new cars. The costs increase from 13.75 Euro/car to 75.00 Euro/car it the cars are transported like this. Because of the low benefits from dismantling EES - very slight increase of the recycling rate (only a few fine cables are lost to the waste or steel fraction), solving no quality problems but increasing the costs and environmental impacts of transport a lot – the cheaper transport will be preferred as long as the legal requirements are fulfilled.

9.2 Quality of steel fraction

The copper content in the steel fraction in Amstetten as well as in Budapest is below the required threshold of 0.25 % even if the EES is not dismantled before shredding. It seems that dismantling EES is not really necessary for quality aspects. Also the value will not be high enough to pay the higher costs for dismantling except they can be used as spare parts.

The copper content in the steel fraction in Budapest is higher than in Amstetten, but also below 0.25 %.

9.3 Splitting of copper into the different obtained fractions

The splitting of copper into the different streams is very hard to assess because copper is a very small part of each fraction – mostly smaller 1 % – and exists in different shapes (cables, wires, pieces, ...). Fine copper particles are spitted to all of the obtained shredding fractions because they hook to other particles. Bigger copper pieces go to the shredder heavy fraction as well as copper containing PCBs. Electric spools that are not completely crushed in the shredder are taken from the magnet to the steel fraction. This spools are hand-picked from the steel fraction.

9.4 Preview on future cars with higher EES content

It seems that shredding is a good solution for recycling of cars even if EES is included. At the moment it is possible to recycle cars without causing high costs to the consumers. If the amount of copper in cars will increase to the double amount of today in some years, the costs for shredding per car will increase only a little – from € 52.66 to € 54.16 – mainly caused by the machinery in this case. So if the raw materials keep the same price shredding will still be an economic solution for ELV in some years.

9.5 Optimisation of the shredding process

The shredding process was actually optimised to be able to handle ELV. The development of this process has been going on for around 50 years now. Improving the shredding process from earlier standards. The potential for optimisation is mainly in the education of personnel and their performed work. A very exact controlling and separation of heavy pieces before the shredding saves much time of maintenance. Further potential for optimisation is in increased recovery from ASR which is pursued in current technology development.

Optical sorting of copper from the steel fraction is not very accurate. Sorting by air jets is very hard if the pieces have those different sizes. Also the colours of rusty iron and copper are quite similar.

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