NewInnoNet | The Near-Zero European Waste Innovation Network

HORIZON 2020 | CSA| WASTE-4a-2014| Grant Agreement No. 642231

Start date of project: 2015/02/01 **Duration:** 30 Months

Identifier:	**D2.3 Report summarising the analysis of the End of Life Vehicle value chain**
Date:	**2016/04/05**
Class:	**Deliverable**
Responsible Partner:	**ARN**
Annexes:	**-**
Distribution:	**Public**
Title:	**Analysis of the End of Life Vehicle value chain**

The project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement no 642231

TABLE OF CONTENTS

VERSION RECORD

Version	Date	Author	Description of Changes
v1	2015/08	Gert Jan van der Have, Alzira Schaap	Document Creation
v2	2015/09	John Bacher, Dirk Nelen	First Review
v3	2016/02	Ulla-Maija Mroueh Tjerk Wardenaar	Second Review
v4	2016/03	Ive Vanderreydt	Final

EXPLANATION OF ACCRONYMS & ABBREVIATIONS

ARN - ARN Holding B.V
ATF – Authorised Treatment Facility
CDAB -Communication and Dissemination Advisory Board
CSA – Coordination and Support Action
D – Deliverable
EC – European Commission
EEA – European Environmental Agency
ELV - End-of-Life Vehicles
ETP – European Technology Platform
EUPC – European Plastics Converters
FMCG – Fast-moving consumer goods
FP – Framework Programme
GA – General Assembly
H2020 – Horizon 2020 The EU Framework Programme for Research and Innovation
ICT – Information and communications technology
IETU - Institute for Ecology of Industrial Areas Poland
IHOBE - Ihobe, S.A.
IVL - IVL Swedish Environmental Research Institute
M – Project month (e.g. M6 stands for month 6 of the project)
MIN – Minutes
NAT – national
NGO – Non Governmental Organisation
OTH - Other
PMT – Project Management Team
PNO - PNO Consultants B.V.
PRE - Plastics Recyclers Europe
R&D – Research and Development
REG – regional
S&T – Scientific and technological
SINTEF - STIFTELSEN SINTEF
SIRA – Strategic Innovation and Research Agenda
SME - Small and medium enterprises
TD – Technical Document
Tecnalia - Fundacion Tecnalia Research & Innovation
VGW - Van Gansewinkel Groep B.V.
VITO - VITO nv
VTT - VTT Technical Research Centre of Finland
WEEE - Waste Electrical and Electronic Equipment
WFD – Waste Framework Directive
WP – Work package

1. MANAGEMENT SUMMARY

Passenger cars are often considered to be the most expensive mass-consumer goods, with global sales volume reaching towards almost 89 million units globally. Irrespective of economic turbulences, the car industry is selling more new vehicles year on year, especially in rapidly developing nations.

The EU is not only a significant car making hub, it is also the basis of best environmental practices along the vehicle life cycle. This includes the environmental sound processing of vehicles which are economical or technical outdated. As a waste product, the 'End-of-Life Vehicle' (ELV) still captures economic value as a source of second-hand parts, high grade metals and engineering plastics.

A wide array of value chain stakeholders is capable to achieve a gross material recycling percentage of minimum 85% by weight, in many EU Member States. ELVs are often regarded as a true example of circular economy and 'near zero waste' performance.

The NEW_InnoNet project is funded by EU Programme Horizon 2020; it is an initiative to establish a European platform for stakeholders aiming to show how the concept of circular economy can be further enhanced and stimulated.

This report provides a comprehensive overview of all industry actors and their respective operational skills. To create basis for innovation roadmaps and a common Strategic Research and innovation Agenda (SRA), it is necessary to achieve clear understanding of the performance of the ELV value chain.

This leads to identification of bottlenecks throughout the value chain, of which a selection is prioritised by using the Multi Criteria Decision Making (MCDM) method. Most significant bottlenecks hampering further improvement in quantity and quality are:

- Inadequate performance of the separation, sorting and refining technology
- Inadequate performance of vehicle dismantling and reuse application
- Limited and low quality application outlets of non-metallic ELV materials
- Inadequate performance of ELV collection and monitoring
- Low-cost of energy recovery and landfilling alternatives compared to material recovery

The impact of these bottlenecks have been weighed by four individual criteria, which are (1) Reducing losses of plastics (2) Reducing losses of ferrous metals (3) Reducing losses of non-ferrous metals and (4) Reducing cost of recycling

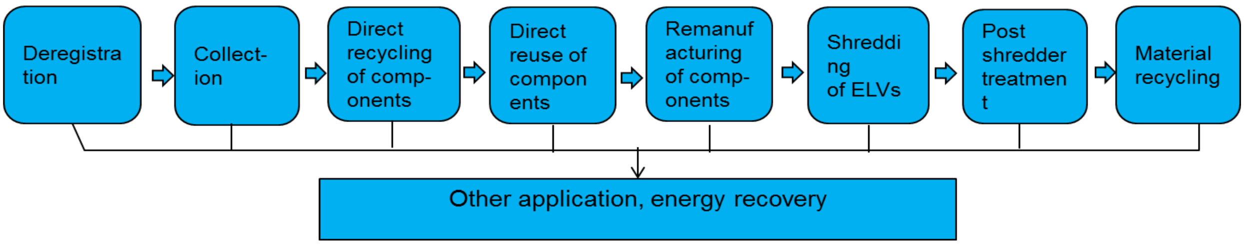


Figure 1: Summary of the European ELV value chain

2. OVERVIEW OF THE DELIVERABLE

WP:	**WP2**
Task:	**Task 2.4 Value chain analysis for End of Life Vehicle waste**
Title:	**Analysis of the End of Life Vehicle value chain**

2.1 OBJECTIVE

The analysis provided in this report intends to create a firm foundation for subsequent activities, to be developed along the New_InnoNet project. This report includes a comprehensive and detailed value chain analysis, complemented with a list of key bottlenecks. These are the key factors hampering further integration of circular economy, zero-waste strategy and qualitative improvement of recycling.

The methodology towards the value chain analysis and bottleneck analysis is further explained in Chapter 2.3 and in the report *Common methodology for bottleneck analysis* (New_InnoNet 2015).

This report provides insight in: the definition of the scope; description of the value chain; identification of bottlenecks; analysis of bottlenecks.

2.2 SCOPE

The recycling chain of End of Life Vehicles (hereafter ELVs) includes a wide array of actors and operations. It is a closely monitored waste stream, since it forms part of national and European legislation, including mandatory recycling and recovery targets.

ELVs as a waste stream occur due to ageing or damaging of vehicles. Within Europe, the gap between 'Best Practice' solutions and substandard practices is very wide. Reuse of parts and materials can provide a sound business case, also for illegal and criminal operators. Therefore the level of governmental control and enforcement is traditionally high in the vehicle end-of-life chain. Export of ELVs is forbidden, unless the car wreck is sufficiently depolluted. In that case the vehicle is 'green-listed' for export.

Parts demand is largely market driven, dictated by components which traditionally wear out quickly such as alternators, starters and hydraulic steering parts; and by parts which are interchangeable between car models and brands.

Materials arising from ELVs are metals, such as ferrous, non-ferrous (copper, aluminium, lead) and precious and minor metals. Furthermore hard plastics and fibrous materials (from seating and cladding), glass and minor elements such as rubber and wood are present in end of life vehicles.

2.3 ANALYSIS METHODOLOGY

A common methodology was used in the analysis of the three value chains: ELVs, Waste of Electrical and Electronic Equipment (WEEE) and Plastic Packaging. The overall objective of the analysis was to evaluate where and how the change towards near zero-waste value chains can be made by overcoming the major bottlenecks of technical and non-technical nature. Secondly, the analysis should create a basis for subsequent project activities, including innovation roadmaps and strategic research and innovation agenda. The key stages of the analysis are described below.

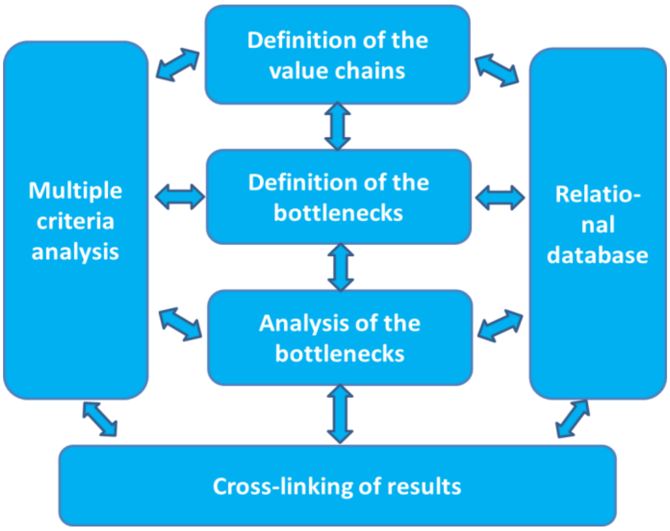


Figure 2 Description of the stages of analysis of the value chains to identify best practices and bottlenecks

- The current best practice value chains were defined in order to enable identification of bottlenecks limiting the performance in the chain and to enable collection of data for analysis and prioritisation of the bottlenecks. The value chain covers the whole material cycle. Main focus is in the waste handling operations from waste discarding and collection to processing stages which prepare reusable parts or raw materials fulfilling the specifications of the prevalent manufacturing processes. Other parts of the cycle cannot be excluded because they are linked and have influence to the perfomance of the waste value chain.
- The bottlenecks, their causes and impacts were identified and described as explicitly as possible. The bottlenecks were defined based on the project goal and scope as factors that limit transformation towards zero waste value chains.
- The significance of the bottlenecks was analysed based on the economic value and improved material and environmental efficiency that could be attained by removal or reduction of the limiting factors. First the criteria which describe the impact of removal of the bottlenecks were selected. The following types of criteria were chosen and further adapted depending on the characteristics of each value chain:

a. Economic: Lost value and additional costs due to the bottleneck;

b. Material efficiency: Losses of materials due to the bottleneck;

c. Environmental: GHG emissions due to the bottleneck;

d. Other: Technical and economic feasibility of removing the bottleneck.

The criteria performance was evaluated using either quantitative, semi-quantitative or qualitative information describing the consequences of each bottleneck. The bottlenecks that should be removed were prioritized using this information. Either panel or questionnaire based multiple criteria decision making method was used in order to arrive at a list of prioritized bottlenecks.

- The results of the analysis per value chain were cross-linked to define commonalities between the chains and bottlenecks, so that uniform solutions applicable to several waste streams could be identified.
- Creation of a database of potential technological solutions of the bottlenecks to be used and further developed during subsequent project activities.

3. VALUE CHAIN END-OF-LIFE VEHICLES

3.1 CONTEXT

Millions of vehicles are wasted every year around Europe. Official statistics (Eurostat, 2013) count up to 7 million vehicles, but other studies assume that about 14 million are discarded (Fig 3). The arising of these ELVs is largely dependent on economical business cycles, which impact vehicle sales, export potentials and subsequent discarding of ELVs.

In the next subchapters the value chain of ELVs is described in an extensive way, from policy background towards all products gained during the recycling process.

The average age of a vehicle becoming waste is slightly increasing in the EU, but mostly impacted by incentives such as scrapping premiums and second hand sales potential. Before vehicles are entering the end-of-life chain, they remain longer on the road and are often exported. But at some stage, the car has become at the end of its service life, technically or economically. Typically the usage age span of vehicles is the highest of all consumer products. It is expected that by 2020, around 100 million vehicles will be scrapped (Cheah, 2010).

In the EU27, official statitiscs count annually between 7 and 9 million vehicle units, depending on the economic conjucture. However, inofficially this figure is calculated much higher towards around 14 milllion units (Denmark, 2008).

Then it becomes part of a century old metal recycling chain. Next to construction scrap, ELVs are the most important source of scrap metal for the metal recycling system. Between vehicle discarding and application of recycled metals, a complex system of actors, operations and products are capturing the value of an ELV.

ELV treatment is facing multiple challenges, of which the most important is the change in vehicle composition. In addition, the market for parts reuse and material recycling is constantly moving. One aspect always remains the same: proper treatment of ELVs results in strong environmental and economic benefits, while improving vehicle life cycle emissions substantially.

Thousand	2005	2010	2020	2030
EU-25	12 770	14 077	16 642	18 756
EU-25 Sat 62%	12 770	14 077	16 627	18 704
EU-15	11 583	12 595	14 565	16 206
EU-10	1 187	1 482	2 077	2 550
EU-10 Sat 62%	1 187	1 481	2 063	2 498

Figure 3: Number of ELVs, 2005 – 2030, baseline projection and alternative saturation levels (Denmark, 2008)

3.2 POLICY DRIVERS

Historically, many recycling activities are developed as a result of a market-demand driven economy. Commercial gain has been made since centuries at ferrous and non-ferrous metals, while plastics recycling was developed late 20th century. Both formal sectors and informal sectors are involved, the latter mainly in less advanced nations.

Systematic and monitored recycling started in late nineties, as a means to improve environmental standards in car recycling and to collect abandoned vehicles more efficiently. The introduction of producer responsibility required action from car producers, and is the basis for current European legislation. The policy first appeared in the early 1980s in a few European Member States, especially for packaging waste, and since then it has continuously spread around the EU (and abroad).

Producer responsibility is about making sure businesses that manufacture, import and sell these products are responsible for their end of life environmental impact. The regulations require businesses to: (1) minimise waste arising from these products and promote their re-use; (2) ensure the waste products are treated and meet recovery and recycling targets for the waste materials; (3) design products by reducing material use and enhancing reusability and recyclability

However, European regulation is interpreted (differently) in national legislation, as is the national government reporting to the European Commission. Still, Member States are responsible for reporting the national compliance results. The different ways of implementing leads to incomparable data (Agency, 2008).

High impact European regulations are:

- **2000/53/EC (ELV Directive):**

Addressing waste arising from end of life for automotive products - only M1 (passenger) vehicles and subcategories. The ELV Directive has been the driving force to improve environmental (depollution and phase out of hazardous materials) and resource efficiency performance (recycling and recovery subquota). Implementation methods, such as efficiency calculation might vary between EU Member States.

- **2005/64/EC (Reusability, Recyclability, Recoverability –RRR- Directive):**

Dealing with the theoretical reusability, recyclability and recoverability of the whole vehicle based on its material composition (transposed on globalUNECE level). The RRR Directive is part of the Whole Vehicle Type Approval process, which is obligatory to registrate new vehicles in the European Union. Car Manufacturers should prove that the materials used can be technically recycled.

2006/66/EC (Battery Directive):

Intends to contribute to the protection, preservation and improvement of the quality of the environment by minimising the negative impact of batteries and accumulators and waste batteries and accumulators. This not only concerns the portable household batteries, but also industrial automotive batteries, such as lead acid batteries and High Voltage vehicle propulsion batteries.

2008/98/EC (Waste Framework Directive):

Provides the overarching legislative framework for the collection, transport, recovery and disposal of waste, and includes a common definition of waste. It is based upon the waste hierarchy: prevention, reuse, recycling, recovery, incineration, disposal. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The WFD has introduced the 'Polluter Pays' and 'Producer Responsibility' priniciple in the legal system.

3.3 ACTORS

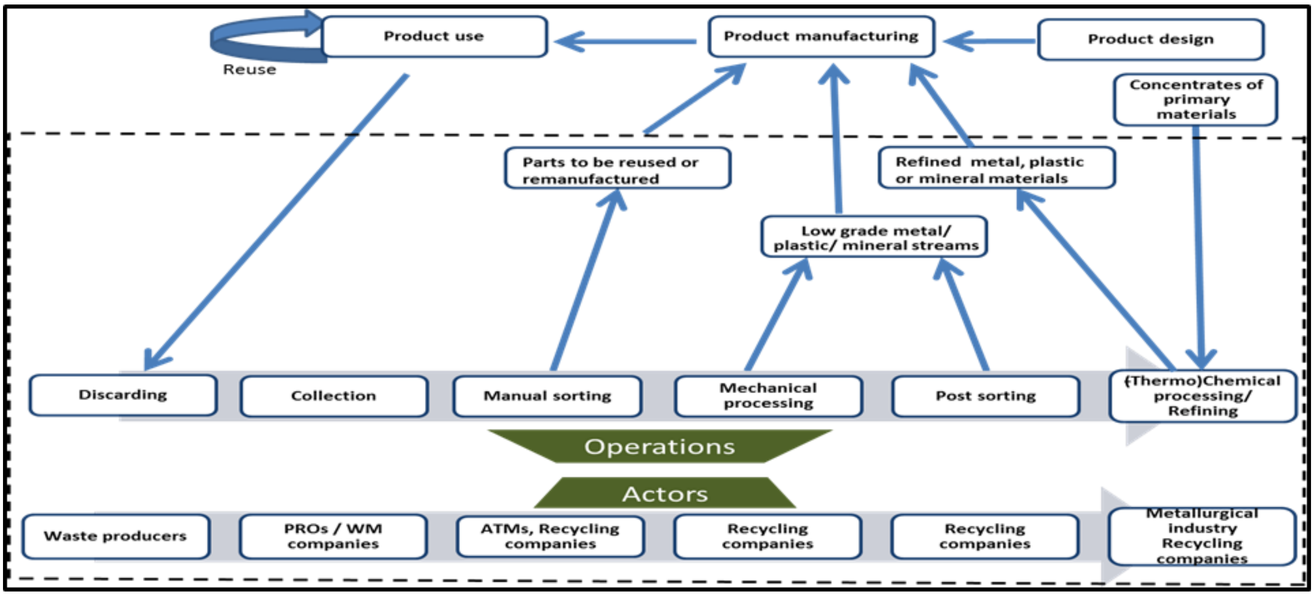


Figure 4: Process chain of ELV waste, excluding material loss due to incineration and landfill

3.3.1 Waste suppliers

A vehicle has become an End-of-Life Vehicle -or 'waste' as soon as there is no economic value to maintain it as a vehicle. Stakeholders in this first step of the chain are:

- *Private individuals:* In case the vehicle is economical total loss, the private individual delivers the vehicle at an Authorised Treatment Facility (ATF) or a middleman. The ELV should be accepted against no cost and the last owner should receive a Certificate of Destruction (CoD). The CoD takes off all liability from the shoulders of the last owner.
- *Insurance companies:* In case vehicles have been subject to accidents and are technically total loss, insurance companies are auctioning off the ELVs to groups of preferred dismantlers. Vehicle users can both be private persons as well as large fleet owners.
- *Car dealerships:* When individuals trade in their old vehicle at the car dealer in return for a newer model, and when the old vehicle has no direct resale or export value, the dealership trades the vehicle to a dismantling company.
- *Vehicle manufacturers / importers:* The ELV directive stipulates motor vehicle manufacturers and importers to take back all on-sale vehicles and vehicle batteries at the end of their life, ensuring that they are treated in an environmentally responsible manner.
- *Miscellaneous:* 'Other suppliers' often include fleet-owners with proprietary ELV trading systems, which can be police, road inspection or other agencies

Associated Stakeholders:

[Vehicle owners] [Insurance companies] [Dealerships] [Fleet owners]

3.3.2 Producer Responsibility Organisations

The *Original Equipment Manufacturer* (OEM) is under European law assigned to organise take-back of its passenger vehicles, when they reach end-of-life stadium. OEMs may either setup their own system or assign a third party to execute these regulations. ELV take-back is organised differently per country, both from a governance point of view – the way of legislation implementation - as well as take-back methods.

A *Producer Responsibility Organisation* (PRO) is collectively representing a group of manufacturers/importers, to fulfil their legal requirements on waste arising. This allows the OEM to focus on their key objective, i.e. designing and marketing their vehicles and other products.

Multiple waste streams in Europe are subject to the European Waste Framework Directive. This standard-setting initiative of the European Commission has created waste stream specific European guidelines. The ELV Directive requires OEMs to take responsibility for their end-of-life goods and describes legal criteria. This includes phasing out of hazardous construction materials, achievement of recycling quota and free take back of ELVs.

However, implementation and enforcement of the ELV Directive is in the hands of national authorities. It is obligatory to inform the national government on the recycling performance, of which the most important requirement is to reach 95% recovery of the vehicle weight, 85% should account as material recycling.

Associated stakeholders:

[Car manufacturer] [Producer Responsibility] [Environmental authority] [Enforcement inspectorate]

3.3.3 Authorised Treatment Facilities and Recycling companies

An Authorised Treatment Facility (ATF) is a company which is formally accredited, permitted and equipped to take back and depollute ELVs and is the prime entity to issue Certificates of Deconstruction. This can be a car dismantling company, but also workshops, shredder companies and other businesses..

Along the chain of treatment of an ELV, many recycling companies are active to depollute the vehicle, to disassemble components and materials and to shred the remaining car hulk. Other specialist companies are taking in the dismantled materials and fluids, as well as materials arising during the shredder process. Although scrap consuming metal producers are not acclaimed to be 'recyclers', they actually are – similar to companies accepting non-metallic shredder residues (minerals, fibres, plastics, rubber, wood).

Associated stakeholders:

[Collection point] [Dismantling stations] [Shredder sites] [(De-) registration authority] [Scrap traders] [Local authority] [Specialist recycling company]

3.3.4 Metallurgical industry

The metallurgical industries can be broadly divided into primary, secondary, and miscellaneous metal production operations. Primary production of metals involves the processing of ores to extract the metal they contain and the mixture of metals, sometimes with other elements, to produce alloys.

Secondary metals refers to the manufacturing of alloys by utilising metals from scrap and salvage, as well as ingots. Miscellaneous metal production encompasses industries with operations that produce or use metals for final products.

Metallurgy is also the technology of metals: the way in which science is applied to the production of metals and the engineering of metal components for use in products for consumers and manufacturers.

Associated stakeholders:

[Primary - Secondary Aluminium] [Metallurgical Coke] [Secondary Brass and Bronze melting] [Copper smelting] [Ferroalloy Industry] [Iron Foundries] [Steel Industry] [Primary - Secondary Lead Smelting [Steel Foundries] [Zinc Smelting] [Secondary Zinc]

3.4 Operations

3.4.1 Discarding

When a vehicle is technical total loss, repair costs are surpassing the value of the vehicle – the vehicle has become an end-of-life vehicle, a waste product. When a car is *technical* total loss, it usually has been subject to an accident. This can both be either a youngtimer or older vehicle. When a car is *economical* total loss, there is no resale/export or reconditioning value although the vehicle might be technically 100% fit; typically this is an old vehicle. In most cases a vehicle is both technical as economical total loss, as repair costs are higher than intrinsic value.

When the vehicle has become a practical waste product, it has also become an official waste product through provision of a dismantling declaration by the ATF. Through this document, all liability has been taken from the consumer, the ATF has become owner of the 'waste', and the vehicle is not anymore registered as a vehicle in fleet databases.

Vehicle discarding in populated areas is relative efficiently organised. However, the more remote the point of discarding is, the more complex it becomes to organise efficient collection and treatment of an ELV. In some countries without proper vehicle recycling schemes, vehicles are abandoned along the road as their value is not significant to cover collection and transportation costs.

3.4.2 Collection

Although the ELV does not represent product value anymore, as a waste product it still contains valuable components and materials. The ELV has become subject to a chain of internationally operating traders, especially in the case of valuable youngtimer ELVs; these ELVs contain a high share of reusable / marketable components. It is formally allowed to import-export ELVs, as long as the vehicles are depolluted from hazardous materials (batteries, seat belt tensioners, etc.) and liquids.

In majority, collection companies are also dismantling facilities or scrap yards. In contrast to e-waste, packaging or other regulated waste streams, the treatment of ELVs takes place at dedicated facilities which are not connected to major waste management companies.

Collection takes place on regional, national and international level. The more valuable an ELV is the more it becomes part of an international trading system.

3.4.3 Manual sorting and dismantling

The final owner of the ELV is the dismantling firm or sometimes a shredder company. In both situations the ELV is mandatory to be depolluted from hazardous and dangerous materials (e.g. airbags, seatbelts, batteries), tyres and liquids (e.g. oil, coolant and fuel residues) in a certain timeframe. These materials enter their specific recycling streams, such as tyre recycling or battery recycling.

The role and business case of the dismantling company is to understand the economic value of the components for resell purposes. Depending on the quality and market demand for parts, vehicles are disassembled, eventually stored, and parts are resold to private consumers, to workshops and core buyers. Traditionally this is 'over the counter' and by phone, but usage of online channels is accelerating.

A dismantling company may vary from a small 'mom and dad' SME or belong to a larger group of companies. Also, shredder firms may act as vehicle depollution station, as well insurance companies may run their own dismantling centres. *Core buyers* are service providers towards the remanufacturing industry and purchase parts from the 'free market' (such as dismantlers) in order to fulfil their client needs.

3.4.4 Mechanical Processing

When the ELV does not possess any reuse value, the independent dismantler sells the stripped car hulk to a shredder company. In some cases in Europe, dismantling and shredding are part of the same entity. In most of Europe it is legally binding to process an ELV in a shredding installation, but in a few countries ELVs can be cut by scrap shears. The objective of the mechanical processor is to extract all valuable materials. Traditionally this consists of the main metals fractions (ferrous & non-ferrous), but increasingly also materials such as plastics.

Shredder technologies focus on the optimal liberation of metals of the scrap infeed. By means of hammers, wind sifters and more advanced technologies, ELV hulks are grinded into fist size pieces. ELV Shredders are available from small 500 hp mobile versions to 10.000 hp stationary shredders. The large size shredders are energy intensive and require strict regulations on noise, odour, air and soil impact.

3.4.5 Post Sorting

About 70% of an ELV is made from metal, the remainder is a combination of plastics (PP, PE, ABS, etc.), (in-) organic fibres (e.g. PUR, hemp), minerals (e.g. sand, glass particles) and to a less extent rubber and wood. Only the metals and a small portion of plastics have a net positive value, while the remaining percentage has no or a negative market value. The remaining heterogeneous waste fraction is called Automotive Shredder Residue (ASR).

To fulfil regulatory-driven recycling targets and reduce landfill/incineration costs, shredder operators are investing to upgrade their post sorting process. In majority this process is a set of mechanical steps (e.g. sieves, air tables, hammermills, magnets, eddy currents, density separation, sensor-based sorting), which provide material streams capable for a material recycling application. To a less extent, treatment technologies like gasification or pyrolysis are applied, to regain both material (metals) and energetic values (syngas, heat, oil).

3.4.6 Thermochemical Processing

The recovered materials from an ELV – or 'secondary commodities' – are supplied to final processors, in different quantities and qualities. Steel, aluminium and copper are relying on century old recycling systems and can be supplied with near virgin qualities. Technologies to separate other materials are in their infancy, and outlet markets are limited.

Shredded steel is sold globally to Electric Arc Furnaces (EAF - 100% scrap) or Blast Oxygen Furnaces (BOF -

upto 20% scrap as a cooling agent). Plastics derived from automotive and electronics are sorted, refined and blended by a limited number of specialist plastics converters in Europe. Fibres and mineral fractions possess contaminated characteristics, which are not accepted by final users. Therefore alternative treatment steps are necessary to reach acceptance criteria. Aluminium and copper are melted at dedicated installations, together with other materials from other product streams. This might be construction scrap, WEEE derived metals, or production waste.

3.5 Products

3.5.1 Parts for Reuse

The value of an end-of-life vehicle is determined by the presence and quality of components for reuse. The market of parts for reuse consists of several stakeholder groups: private people who are servicing their vehicle; workshops and garages; and core buyers. The last group is purchasing parts for the remanufacturing sector.

Online sales channels achieve increasingly more popularity – both general market places as specialist trading applications. Software is capable to predict demand for reused parts, nationally or globally, enabling the dismantler to only take out parts which are really in demand.

The client base for reused parts is developing quickly. Reused parts with a transparent background and determined quality are increasingly accepted by leasing companies as a low-cost repair alternative for vehicles. The most popular components for reuse are: gearboxes, starters/dynamo's, whole engines, lightning units, tyres and wheels, valve housing, turbochargers, suspension elements, bodywork, air conditioning pump.

There is strong dependency between the acceptance and value of reused parts and the level of vehicle complexity. Modern vehicles tend to be constructed in a compact way, which makes parts time-consuming to disassemble. This increases the part cost, which makes it less attractive for resale in some cases. At the other hand, replacement of parts is getting more expensive overtime, which makes use of second hand parts an attractive alternative.

3.5.2 Materials for Reuse / Components for Recycling

As a trader, a dismantling station knows exactly the intrinsic value of the parts, but also the materials on-board of the ELV. Catalytic converters, lambda sensor, wiring harnesses, engines and other high (material) value components are dismantled as soon the prices are justifying the manual labour cost. Apart of valuable components, some parts and fluids need to be removed from the ELV for legal reasons.

Materials and fluids are separately stored, and collected and treated by specialist recycling companies. The key challenge for a dismantling company is to understand values of materials, especially on the new components and materials.

There is a strong dependency on automotive material compositions. In relation, there is an opposite view on materials between a manufacturer and recycler. The objective of the manufacturer is to use the lowest cost materials, phasing out and substituting highly valuable -mostly metallic- materials. The objective of the recycler is to regain highly valuable materials, separate these for supply for the recycling market.

3.5.3 Secondary Material streams

Secondary materials are the materials which originate from a product formation process, either generated as post-production or post-consumer. Initially, economic value is the key driver to recycle materials, but increasingly recycling targets determine the level of recycling of products. Economic gain can be made on products and secondary metals, but ELV plastics, glass, fibres and other materials have a net negative value. Since the material recycling quotum of 85% can only be achieved by processing non-metals, the negative economic buurden has to be managed by the value chain stakeholders.

Concerning ELVs, the material composition is gradually developing from utilisation of specific metals, towards a diversified material mix with growing polymer-based content. In the seventies up to 80% of vehicle weight was based on easily separable metals – it is forecasted that by 2020 this has shrunk to 60%. For more details on material compositions, see figure 5 and chapter 4.The trend to reduce vehicle weight poses new challenges to the end-of-life chain.Use of conventional plastics is gradually growing, but more extensive is the contribution of 'other' materials, such as minerals (glass), rubber, fibre (isolation-seating) and fibre reinforced plastic contents in current trends.

The recycling system and technologies for metals has been mature since many decades. Scrap metal has become a vital element of metal making. But for polymer based materials, the technological and economical challenges are immense. Diversification in characteristics impedes the technological recyclability, while price-setting for secondary plastics are still based on virgin oil prices. Application of secondary materials is outlet and market driven. The availability of outlets for post-consumer non-metals is rarely available as there are shortfalls in qualities, compared to post-production offshoots.

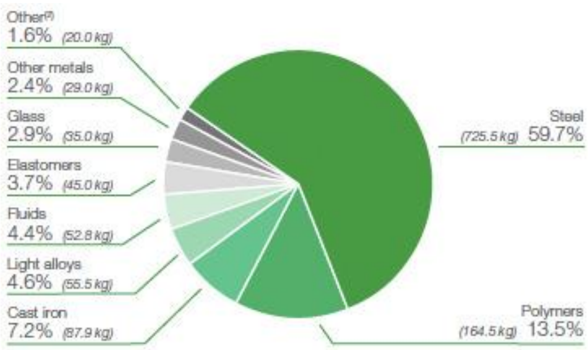


Figure 5: Average vehicle composition from FIAT group (FIAT Group, 2012)

3.5.4 Refined material streams

The key distinction between metal processors (steel, copper, aluminium) and other convertors of non-metals is that the first have installed and organised themselves to reprocess scrap metal. Traditional plastics producers are not capable to take in secondary plastics with contamination levels; instead, a new playing field has arisen of specialist plastics treatment companies, which produce specified recyclates which are directly used by injection moulders and similar product makers.

Electric Arc Furnaces (EAF) produce steel derived from 100% scrap metal, as well by-products which are concentrated in the slags. Blast (Oxygen) Furnaces (BOF) produce steel from both primary (80%) and secondary (20%) resources, steel scrap is used as a cooling agent to balance the furnace temperature. High quality steel products (such as Ultra High Strength Steel – UHSS- used for automotive) is created by BOF's.

Aluminium and copper refiners often rely on scrap metal, although virgin materials are always required to reach the optimum required quality. Interviews with experts in the field reveal that due to high energy/electricity consumption, aluminium and copper recycling plants have only economic and operational feasibility in case they are located in regions with low energy pricing.

Treatment of residues, such as slags from steelmaking, gains relevancy since metals are increasingly alloyed with more exotic and valuable metals, which end up in the residues.

4. STATE OF THE ART RECYCLING REALISATION

4.1 INPUT MATERIALS

Materials	Vehicle Content /kg	% of total average
Cast Iron	149	10,70%
Conventional Steel BOF	432	31,03%
Conventional Steel EAF	160	11,49%
Stainless Steel	22	1,58%
HS Steel	144	10,34%
Cast Alu	84	6,03%
Wrought Alu	20	1,44%
Magnesium	3	0,22%
Copper/Brass	19	1,36%
Zinc	5	0,36%
Other Metal	15	1,08%
Plastic	105	7,54%
Rubber	61	4,38%
Glass	42	3,02%
Fluids/lubricant	84	6,03%
Other materials*	47	3,38%
Total	1392	100%

Figure 6: Average vehicle composition \ (Cheah, 2010) * Wood, organic, textile, etc.

Data provided in this table is derived from a large analysis by the Massachusetts Institute of Technology (MIT) (Cheah, 2010) and reflects the average composition of a US vehicle, propelled with a conventional propulsion system (diesel or petrol) and produced in 2000. European vehicles are of lighter weight than their US counterparts, the percentual material composition is assumed to be equal. A vehicle produced in 2000 is expected to enter the recycling system between 2015 and 2020.

There is no reference to materials such as Nickel, Cobalt, Rare Earth, Lithium Oxide, Manganese, Graphite/Carbon and Fibre Reinforced Plastic. After all these materials were exotic for a vehicle produced in 2000. However, these materials are relevant for vehicles with electric propulsion. Since the rapid development in this category, there is no average data available. Electric vehicles benefit from higher plastics levels, as the light weight advantage has a direct impact to vehicle reach.

In order to reduce exhaust emissions, the two main construction trends are: (1) light weighting by innovation of existing materials or application of substitute materials; and (2) development of new drive trains powered by alternative energy sources (CNG, Hybrid, Full electric, Fuel Cell). All this means a gradual shift in material use and on the long run on material recycling.

4.2 MATERIAL TRENDS

The gradual shift in material use is dominated by the more extensive application of aluminium, high strength steel (which is often heavily alloyed) and non-metallics such as hard and foam plastics (incl. composites), glass and organic materials.

The last category has a severe impact on the vehicle recycling system. Since metals are highly recyclable, non-metallics are difficult to sort, have little economic value and have lower emission burden than metals.

Interviews with metal-making companies reveal that the industry can hardly function without scrap metal supply and that pricing of scrap is increasingly disconnected of virgin raw material pricing. For polymer-based products, recycling is still in its infancy. Innovation in input materials requires – at the end-of-life- also innovation in recycling systems and technologies.

In the light of the European ELV Directive, producers are responsible to reach a 95% recycling and recovery rate by weight for ELVs. Higher contribution of non-metallics will bring either extensive downcycling of materials or a negative cost burden for either car producers or recycling systems.

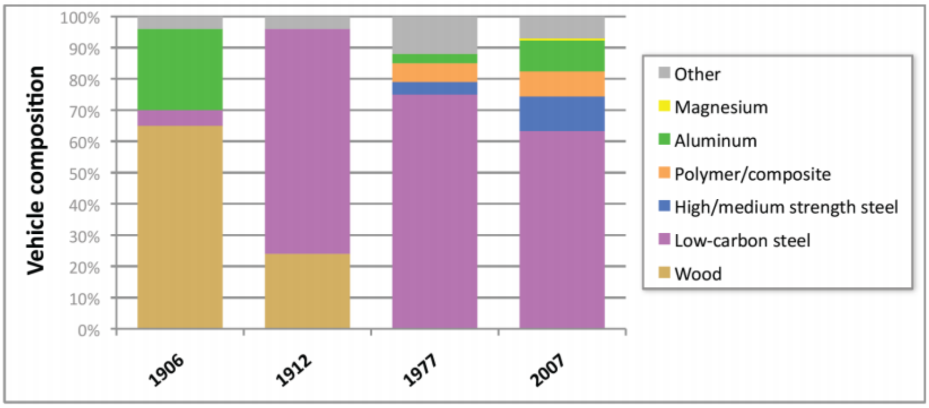


Figure 7: Long-term shift in automotive materials (Taub, 2007)

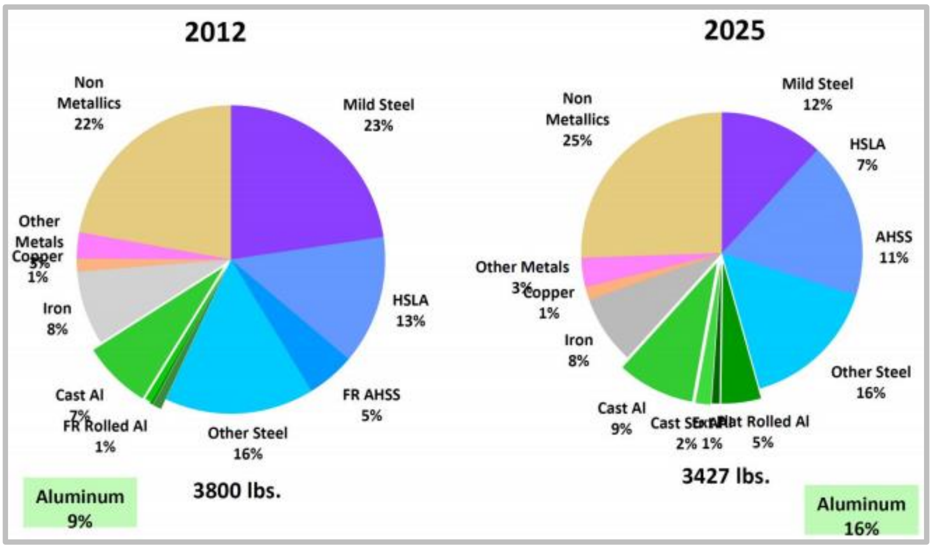


Figure 8: Short term shift in automotive materials (Association, 2014)

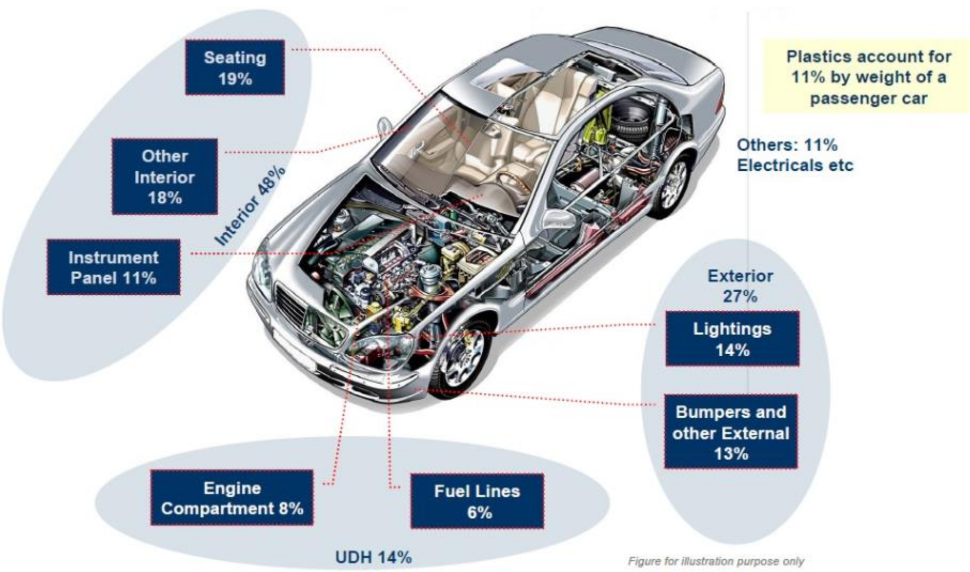


Figure 9: OEM Weight Reduction strategies: Plastic composition of the vehicle (Sullivan)

4.3 RECYCLING RESULTS

When a vehicle is declared End-of-Life, the vehicle is degraded to a waste product. Young (mostly crashed) ELVs might contain many valuable components, for which the owner receives a benefit. For old ELVs the benefit might be low, in some cases even negative.

Recycling systems are based on the principle to gain the most value with the least manual work, especially in high-salary countries. This may vary between Northwest Europe and low salary EU countries. Automation is the standard, while manual dismantling is reduced for materials which are easy to disassemble and have high economic value. Logistics is an important cost burden, especially in large countries with low population. Most important aspect of vehicle recycling is: it's not about the product/material value but the product/material separability (liberation).

Particle size reduction and liberation of materials during the shredding of modern end-of-life products plays an important role in the composition (and quality) of the intermediate recycling streams and the ultimate material recovery and therefore recycling rate (A. van Schaik, 2004).

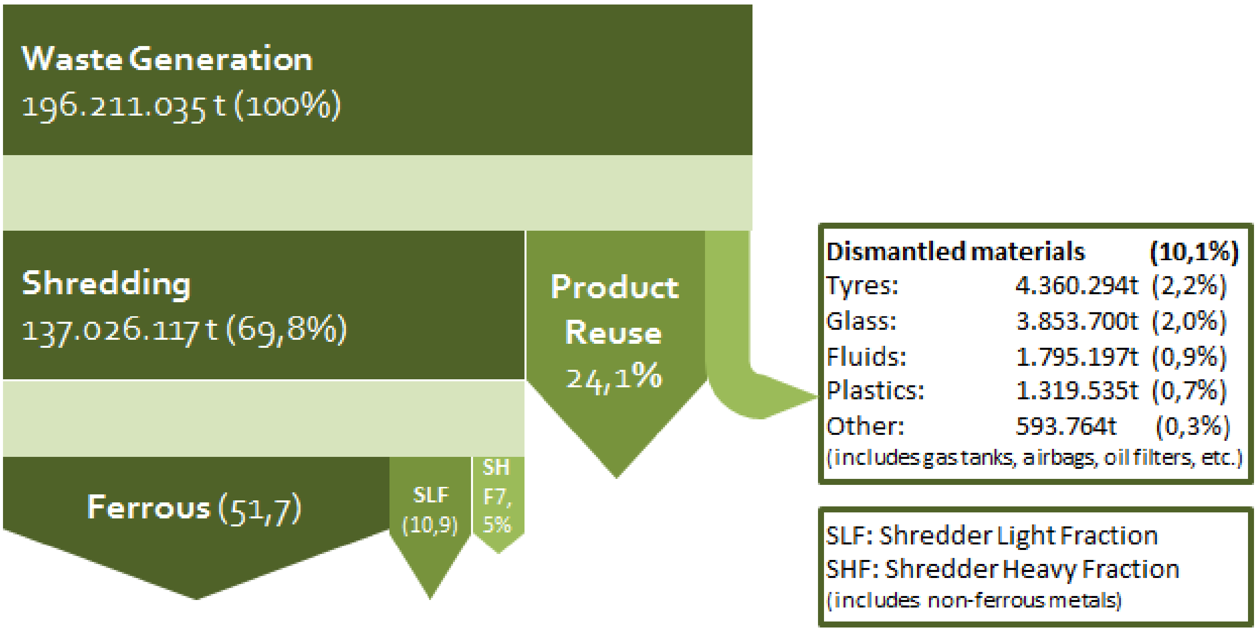
Measuring the recycling rate of ELVs in an effective way is a challenge, as many stakeholders are involved, which sometimes are protective towards their data. The key reason for measuring is the Member State accountability to reach recycling targets as set by the European ELV Directive. Member State regulators may ask additional measures, such as obliging shredding ELVs – instead of shear cutting- or determine fixed product reuse quota.

Cornerstones of effective data measurement are the stakeholder incentive to administer results and the introduction of shredder trials. These trials are held in most European countries to create a benchmark for recycling realisations. A theoretical base is developed by creating a mass balance, selecting a representative ELV fleet, shredding them, and measuring the output streams. This data will than provide basis to calculate aggregate recycling results.

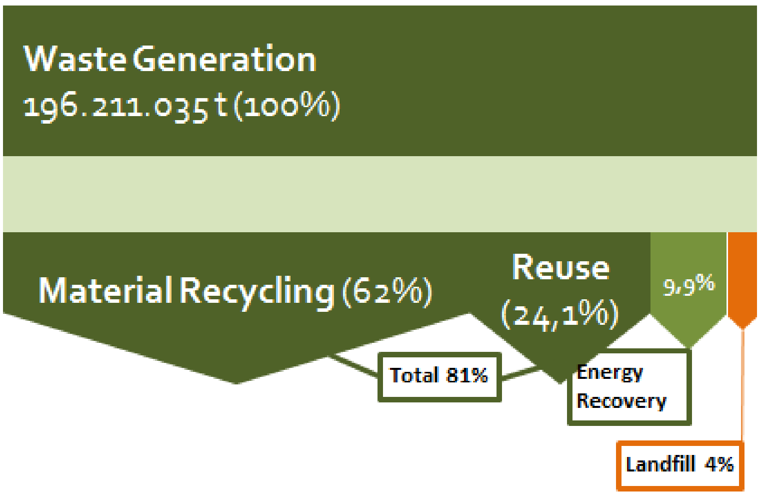
4.4 BEST PRACTISE EXAMPLE

Data provided in this chapter are based upon the realisation in a single Member State, namely the Netherlands. On a European-wide level it is difficult to gather verifiable data. Since ELV recycling structures and calculation methods are differently implemented per Member State, a whole European overview would result in unreliable results. The Dutch situation is considered as a Best Practice because of the transparent way of data generation. It is important to note that the data shown are for the Dutch situation and cannot be extrapolated to other national situations.

Material Mass Balance



Recycling Realisation:



5. DEFINITION OF BOTTLENECKS

5.1 METHODOLOGY

The key objective of defining key bottlenecks is to make clear what the main hurdles are to achieve a higher level of circular economy by working towards a zero-waste value chain in the automotive end-of-life system. The bottlenecks have been identified during expert interviews and have been ranked qualitatively by expert panels.

The list of bottlenecks has been compiled in such a way that it describes the key hurdle and main impacts associated. The material efficiency and cost impacts have been qualitatively evaluated for a selected list of bottlenecks by an expert panel. This has been performed linked to the prioritisation of bottlenecks. The combined results of evaluation and prioritisation of the bottlenecks can be found in the NEW_InnoNET report *Commonalities between value chains* (NEW_InnoNET, *forthcoming*).

The complicating factor is that data in the ELV chain is difficult to obtain as many economic and organisational operators and interests are involved. Available data is often without a transparent calculation or just not reliable (see bottleneck 3). National standards such as regulations and industry practices deviate extensively between EU member states, which impacts reliability of a gross European wide analysis.

As a solution for qualitative data assessment, national data with the best transparent background is taken: the monitored data of ARN in the Netherlands of the automotive end-of-life chain. This forms the basis of the bottleneck analysis.

For every bottleneck the following characteristics are described:

- Name of the bottleneck: Refers to a point of congestion in a process that causes the entire process to slow down or stop.
- Stage: Value chain stage where the bottleneck has the main impact.
- Impact of the bottleneck: The impact is one or more process implications, which are caused by the bottle neck. These can be different by nature.
- Category: The categorisation justifies the type of impact of the bottleneck impact
- Explanation: More technical background is provided to the bottleneck.

A distinction has been made between bottlenecks which can be quantified, and bottlenecks which cannot be quantified due to different factors, these are marked in grey.

5.2 List of Bottlenecks - *Quantifiable*

1	**Bottleneck**	**Inadequate performance of separation, sorting and refining technology**	
	Stage	*Mechanical processing*	
	Impact	Endangering the mechanical material separation and sorting processes qualitatively and quantitatively	**Technological**
		Higher contamination levels in secondary material refining (metals, plastics, etc)	**Economic**
		Hurdling meeting recycling targets in an economic viable way	**Regulatory**
	Explanation:	Vehicle (material) innovation in the construction phase leads to higher levels of intermingled, alloyed and glued material particles. New components are required to be lighter by weight, but with similar or better operational performance. In the current recycling system, this leads to a higher degree of materials with overlapping properties	

2	**Bottleneck**	**Inadequate performance of vehicle dismantling and reuse application**	
	Stage	*Vehicle Dismantling*	
	Impact	Reduced feasibility (time) to disassemble potentially high value components for reuse of recycling	**Economic**
		Higher safety risks for End-of-Life chain due to increasing use of High Voltage Batteries in automotive	**Societal**
		No potential to extract high value but limited applied materials (e.g. RE metals) by technical means	**Economic**
		Software-connected parts are difficult to reuse in the free market	**Organisational**
	Explanation:	Construction complexity and smart connected parts leads to higher effort required to dismantle components for a reuse application. High Voltage components require more safety measures by the collection and dismantling chain. The opportunity to dismantle parts for material recycling decreases as intrinsic material value depletes.	

3	**Bottleneck**	**Limited and low quality application outlets of non-metallic ELV materials**	
	Stage	*Post Sorting*	
	Impact	Investor willingness is limited as no projection can be made on business cases	**Economic**
		Resources are exiting the material chain (incineration – disposal)	**Societal**
		Higher need for innovation in decontamination and immobilisation	**Technological**
	Explanation:	Economic and technical feasibility to sort, separate and refine non-metallics is low, due to the heterogeneous composition of 'shredder waste'. Materials are sorted and due to their low economical value, can only be recycled in low grade applications.	

4	**Bottleneck**	**Inadequate performance of ELV collection and monitoring**	
	Stage	*Collection*	
	Impact	Recycling targets can only be achieved by negative costs	**Economic**
		Loopholes in environmental safe and sound processing	**Societal**
		Monitoring and enforcement are inadequate and information is invalid	**Organisational**
	Explanation	Interpretation of what actually an End of Life Vehicle is, how it should be recycled and how the recycling sub quota should be monitored and judged, is depending on many factors. This creates unclarity for stakeholders and provides incentives for substandard treatment. It further results in a lack of reliable data availability on vehicle registration and composition, ELV collection and vehicle / ELV trade	

5	**Bottleneck**	**Low-cost of energy recovery and landfilling alternatives compared to material recovery**	
	Stage	*Post sorting*	
	Impact	Reducing economical feasiblility of recycling and feasibility of investment to recycling of non-metallic materials and minor metals	**Economic**
		Only lowest quality recycling applications are competitive towards incineration and landfill	**Societal**
		Causing substandard and shady operations to dispose waste streams	**Regulatory**
	Explanation	In some EU Member States, overcapacities (and competition) in incineration facilities and landfill deposits, as well low taxation rates, lead to low gatefees. This creates an unlevel playing field compared to material recycling, of which the operational costs are usually higher than of incineration and disposal.	

4.3 List of Bottlenecks – *Not Quantifiable*

6	**Bottleneck**	**Lack of accreditation and standardisation for ELV recycling operators**	
	Stage	*Collection*	
	Impact	Difficult for contracting parties to select the right partners	**Organisational**
		Higher effort and cost for producers and EPR systems	**Economic**
	Explanation	Requirements (licensing, education, reporting) to start an ELV business are relatively low, while cooperation is often limited between ELV operators. Operational standards vary between stakeholders and involvement of criminal practices is sometimes impacting trust and confidence of contractors.	

7	Bottleneck	**Counterproductive regulation prohibiting improving recycling**	
	Stage	*Sorting*	
	Impact	High costs for recycling operators to develop recycling applications	Economic
		Illegal operators and operations are tempted to avoid regulations	Regulatory
	Explanation	Due to higher higher requirements (e.g. REACH) for raw material production, secondary raw material producers face new challenges. Secondary materials usually contain higher levels of impurities and contamination.	

8	Bottleneck	**Lack of Europe-wide harmonisation in regulation, poor governance and ineffective enforcement of regulation**	
	Stage	*All*	
	Impact	Unlevel playing field for recyclers, unfair trade competition, different taxation and standards on waste management, substandard practices in the End-of-Life chain, lack of insight in vehicle registration flows	Regulatory
	Explanation	The strong variety in implementation levels between Member States, makes it complex to understand what requirements are for legal operators. Illegal operators can easily hide as enforcement is considered as weak.	

9	Bottleneck	**Presence of unwanted substances prohibiting further qualitative application**	
	Stage	*Post Sorting*	
	Impact	Higher contamination rates of heavy metals, persistent organic pollutants, PCB's, oils in metallic and non-metallic fractions	Organisational
	Explanation	Waste materials accumulate substances which are considered as hazardous. Old ELVs may contain mercury, hydrocarbons, PCBs. In the ELV processing, waste is often comingled with other scrap metal.	

10	Bottleneck	**Secondary material pricing is benchmarked against primary material prices**	
	Stage	*Shredding*	
	Impact	Total environmental and societal benefit of recycling are not reflected in material pricing	Economic
		Cost driven producers are solely focusing on primary material infeed	Organisational
	Explanation	Although secondary materials provide a high environmental value, compared to primary materials, this is not rewarded in the final pricing of materials. Virgin materials – especially oil-based- are dominating price setting. When oil prices are weak, plastics recycling is facing economic hurdles.	

11	Bottleneck	**Rapidly changing vehicle designs (model updates), technical compositions and higher contribution of consumers in vehicle design.**	
	Stage	*Dismantling*	
	Impact	Continuous change and challenge of component and material identification - causing knowledge gaps, depleting feasibility for component reuse an material recycling	Organisational

	Explanation	The increasing speed of product adaptation, makes it more complex to understand the product functionality and material composition. There is no communication on material use, between manufacturers and end-of-life operators, therefore the latter have to examine this on their own.	
12	Bottleneck	**Transportability of goods and materials High share of small regional - operating companies in the vehicle end-of-life chain**	
	Stage	*Collection*	
	Impact	Lack of international operations; wide array or absent warranty product and operational standards; lack of investment capacity; unstable long-term forecasts; lack of B2B partnerships; lack of innovation capacity	**Societal**
	Explanation	Transportation costs are decisive whether collection is adequately performed, or not. This counts especially for less populated areas with low ELV arising. It is the key hurdle towards international cooperation.	
13	Bottleneck	**Lack of stability (volume / economic) in secondary material supply chain, is not motivational for material producers to integrate recyclate streams**	
	Stage	*Shredding*	
	Impact	Lack of technological and organisational effort of manufacturers to secure secondary materials as part of raw material chain	**Organisational**
	Explanation	Quality standardisation, which is agreed by a mass of secondary material producers, is largely absent. This is caused by relative low volumes of secondary materials.	
14	Bottleneck	**No incentive for manufacturers to develop 'recyclable' products, as vehicle use phase emissions are dominant design choice in total environmental performance**	
	Stage	*Post Sorting*	
	Impact	Product manufacturers develop more complex and less (practical) recyclable products as vehicle use phase is the leading factor	**Regulatory**
	Explanation	The automotive manufacturing chain is judged upon the final exhaust emissions of their products; not by the recyclability of their products. The reward or incentive to develop recyclable components is limited, except the producer's sustainability awareness.	
15	Bottleneck	**Total arising of ELVs is dropping and ageing, due to 'less accidents', higher safety measures and vehicle exports to foreign destinations**	
	Stage	*Dismantling*	
	Impact	High level of competition to obtain valuable ELVs; less opportunity to fulfill demand for some parts	**Economic**
	Explanation	Due to high second hand value and improved safety features in the automotive, many vehicles are exported instead of scrapped. Young damaged cars are getting scarcer. This impacts the business case of many dismantling companies.	

6. BIBLIOGRAPHY

A. van Schaik, M. R. (2004). *The influence of particle size reduction and liberation on the recycling rate of end-of-life vehicles.* Minerals Engineering.

Association, A. (2014). *Automotive Aluminum Growth and Joining Trends.* Michigan.

Cheah, L. W. (2010). *Cars on a Diet, The Material and Energy impacts of Passenger Vehicle Weight Reduction in the U.S.* Cambridge: Massachussetts Institute of Technology.

Denmark, T. U. (2008). *Projection of end-of-life vehicles: Development of a projection model and Development of a projection model and.* Copenhagen: Risø National Laboratory.

Eurostat. (2013). *End-of-life vehicle statistics*. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do

FIAT Group. (2012). *Sustainability Report.* Torino: FIAT Group Spa.

Miller, L. (2014). *Challenges and Alternatives to Plastics Recycling in the Automotive Sector.* Windsor, Canada: University of Windsor.

New_Innonet. (2015). *Common methodology for bottleneck analysis.* www.newinnonet.eu.

New_Innonet. (2016). *Commonalities between value chains.*

Sullivan, F. &. (sd). *Frost Growth Consulting*. Opgehaald van Automotive Services: http://www.growthconsulting.frost.com/web/images.nsf/0/2DCE1D196E48B7A4652577D9002D8A8F/$File/RS3CH1.jpg

Taub, A. (2007). *The evolution of technology for materials processing over the last 50 years: The automotive example.* Warren, Michigan: General Motors Corp.