Graz University of Technology

Title

Study on recycling of an electric vehicle (E-MILA Student)

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Preface

Hiermit erkläre ich, dass diese Diplomarbeit mein eigenes Werk ist und auf meinen eigenständigen Untersuchungen basiert. Beiträge Anderer (beispielsweise Ideen, Abbildungen, Textpassagen, Tabellen) sind an den entsprechenden Stellen durch einen Quellverweis gekennzeichnet. Weiters erkläre ich, dass diese Arbeit von mir noch nie als Abschlussarbeit oder zur Erlangung eines akademischen Grades eingereicht wurde.

I declare that this thesis is my own effort, based on my original research and articulated in my own terminology. Any use made within it of works of others in any form (e.g. ideas, figures, text, and tables) is properly acknowledged at the point of use. I have not submitted this thesis for any other course or degree.

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Acknowledgements

Many people have contributed, directly or indirectly, to the successful completion of thesis. First and foremost, I would like to thank MAGNA STEYR for giving me this opportunity and my mentor Dipl.-Ing Hannes Rabitsch. His positive attitude and depth of knowledge optimization was the backbone that made this master thesis possible. I appreciate the time he spent with me to discuss thesis related issues and the help and guidance he gave me. I would like to express my deep and sincere gratitude to Univ.-Prof. Dr.-Ing. Ralf Kolleck for his detailed and constructive comments. In particular for the support I had from my advisor from Technical University of Graz, Dipl.-Ing Robert Veit who had been very helpful and available all the time for discussion on master thesis aspects.

I want to acknowledge my parents, my brother and my colleagues especially from MAGNA STEYR who were always available to discuss academic and other pertinent issues. I could not have accomplished this master thesis without having them in my side.

Abstract

The selection of a proper optimum recycling scenario for an electric vehicle has to consider ecological as well as economic effects. After a short overview about the current legal requirements for end-of life vehicles and batteries, the actual status regarding recycling-oriented design and the automotive recycling process in Europe is described. The objective of this thesis is the comparison of three recycling scenarios for electric vehicles regarding recycling costs and profits. The analysis is done for an electric vehicle of L7e segment of project E-MILA Student car. The difference of these scenarios is the treatment of the non-metallic automotive shredder residue (ASR) and the required amount of dismantled parts for recycling. In scenario 1 the ASR is treated for energy recovery only. In scenario 2 and scenario 3 the ASR is treated by different post-shredder technologies (PST) for recycling and recovery (PST Galloo, PST VW-SiCon). The results include the material flow of the recycling process and cost comparisons for the recycling procedure in order to meet the legal recyclability requirements. The calculations according to the standard ISO 22628:2002 are given for each scenario, the material flow and recycling costs and profits are described in detail.

Bei der Auswahl eines optimalen Recycling-Szenarios für elektrische Fahrzeuge müssen sowohl die ökologischen als auch die ökonomischen Auswirkungen berücksichtigt werden. In dieser Arbeit wird nach einer Zusammenfassung der aktuellen gesetzlichen Bestimmungen für Altfahrzeuge und Altbatterien auf den aktuellen Stand im Bereich des Recycling-orientiertes Designs und auf den Recycling-Prozess von Automobilen in Europa eingegangen. Das Ziel dieser Arbeit ist der Vergleich von drei Recycling-Szenarien für Elektrofahrzeuge in Bezug auf Recycling-Kosten und -Gewinne. Die Analyse wird am Beispiel des Elektrofahrzeugs E-MILA Student der Fahrzeugklasse L7e durchgeführt. Der Unterschied zwischen den betrachteten Szenarien liegt in der Behandlung der nichtmetallischen Shredderrückstände und dem Anteil der demontierten Fahrzeugteile. In Szenario 1 werden die Shredderrückstände vollständig energetisch verwertet. In Szenario 2 und 3 werden verschiedene Aufbereitungstechnologien für die Wiederverwendung bzw. Rückgewinnung eingesetzt (PST Galloo, PST VW-SiCon). In den Ergebnissen werden der Materialfluss und die Kosten des Recyclingprozesses zur Erreichung der gesetzlichen Anforderungen ermittelt. Die Berechnung erfolgt nach der Norm ISO 22628:2002. Für jedes Szenario wird der Materialfluss beschrieben und die Recycling-Kosten und -Gewinne im Detail dargestellt.

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1 Introduction:

1.1 MAGNA Group

The MAGNA group is one of the world's largest and most progressive automotive suppliers, founded in 1957 in Toronto, Canada. The range of services are the design, development and manufacturing of automotive systems, modules and components, as well as the engineering and manufacturing of complete vehicles, primarily for sale to original equipment manufacturers (OEM) of cars and light trucks. MAGNA´s capabilities include the design, engineering, testing and manufacturing of automotive interior systems, seating systems, closure systems, metal body & chassis systems, mirror systems, exterior systems, roof systems, electronic systems, power train systems and complete vehicles. Presently the MAGNA group consists of 240 manufacturing operation sites and 76 product development, engineering and sales centers in 25 countries. The locations are shown in Figure 1-1. (1)

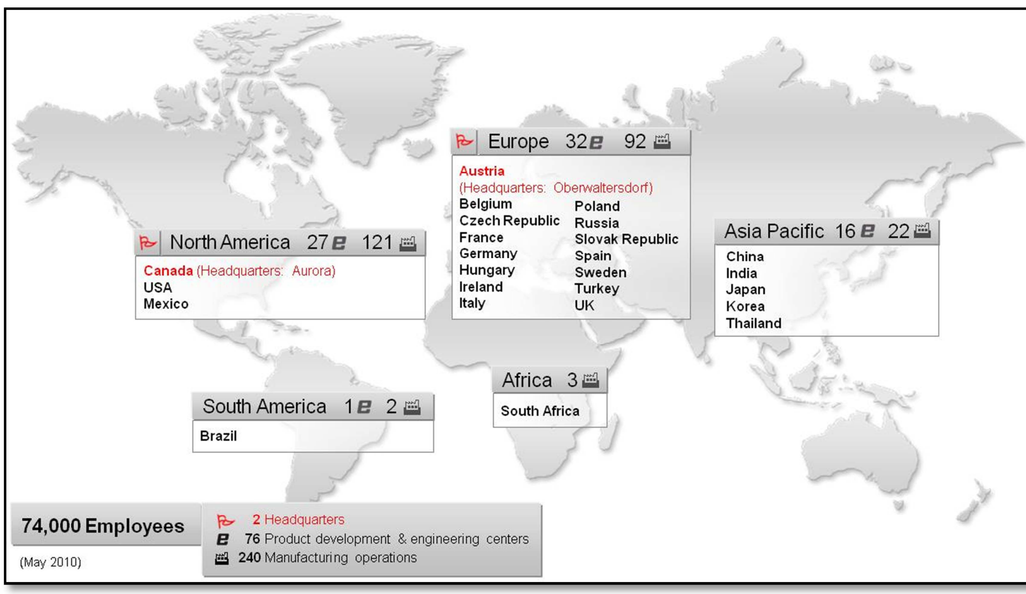


Figure 1-1: Locations of manufacturing operations and engineering centers of Manga group worldwide (Source: MAGNA STEYR)

MAGNA STEYR India Pvt. Ltd. is a co-operation between MAGNA STEYR and MAGNA POWER-TRAIN bringing the dynamic combination of over 100 years of vehicle and drive train engineering experience to India. MAGNA STEYR India offer world class technology, skills and experience to Original Equipment Manufacturers (OEM) in Pune.

1.2 Description of the E-MILA Student Project

The idea of E-MILA student project was initiated by MAGNA STEYR. It is a master thesis project of six students studying Production Science and Management at the Frank Stronach Institute (FSI) of the Technical University of Graz (TUG), supported by automotive specialists of MAGNA STEYR. The project idea was initiated by Mr. Lukas Wechselbergar. The initial idea was to build the movable prototype of the E-MILA Student. Taking into consideration of execution time, manpower and project budget, we have decided to do virtual design for an electric vehicle in the L7e vehicle class. This virtual vehicle design has been sub-dived six master theses and consequent master theses of E-MILA Student are:

1. Market Study for an electric city car (E-MILA Student)
   by D.I. (FH) Michael Karl Preiss.
2. Concept for the development of an urban electric vehicle
   (E-MILA Student) by DI (FH) Lukas Wechselberger.
3. Chassis-, Drivetrain and storage-Layout for an electric City Vehicle
   (E-MILA Student) by DI (FH) Stefan Eitzinger.
4. Homologation and Packaging Study of E-MILA Student
   by Mr. Praveen Kumar Madeshi.
5. Supplier Quality Assurance toolkit (E-MILA Student)
   by DI (FH) Denial Janoach.
6. Study on recycling of an electric vehicle (E-MILA Student)
   by Mr. Muttumula Veera Bramheswara Swaroopa Nandan Reddy.

Since many years the automotive industry has been confronted several problems like environmental effects (pollution and global warming), traffic jams, high fuel costs and parking problems in the megacities due to increasing number of vehicles etc. Small electric vehicles can resolve some of the mentioned problems, even though they have some market adaptive barriers like short driving range, long battery charging time and short battery life. But every year research and development is progressing to improve these limitations. There is ongoing discussion on the effectiveness of the electric car in terms of carbon dioxide (CO2) emissions because most of the countries are producing electricity by burning fossil fuels. But it will surely help to transfer the pollution from cities to less polluted areas.

E-MILA Student is a student version of an Electric MAGNA Innovative Lightweight Auto. The aim of the E-MILA Student project is to develop an electric vehicle for cities and megacities, taking into account the needs of the daily travelling customers. The target is to develop a reasonably priced electric car in the L7e vehicle class which meets the requirements of the majority of young and old people. The L7e segment limits the possibilities in design and development regarding the fulfillment of safety and packaging requirements compared to the vehicle class M1 and other segments. But the major constraint for E-MILA Student is to build without compromising the safety with a vehicle mass of maximum 400 kg excluding the mass of the lithium ion battery system.

A strong focus is laid on the following targets and product features:

- Safety features comparable to M1 category.
- Affordable price
- Modern Styling
- Environmental friendly materials

Vehicle categories are shown in Table 1-1. The category L is represent lightweight vehicles, category M is represent passenger vehicles and category N is represent goods carriage vehicles.

Vehicle Categories						
Category	Type	Number of Wheels	Top Speed (Kmph)	Power for Electric Motor (KW)	Engine Capacity (CC)	Mass (kg) (excluding batteries)
L1e L2e	Moped	2	4	4	≤50	
		3	≤45	4	≤50	
L3e L4e	Motorcycle	2	>45		>50	
		3	>45		>50	
L5e	Tricycle	3	45		>50	
L6e	Light quadricylce	4	≤45	4	≤50	≤350kg
L7e	Quadricylce	4		15		≤400kg
M	Motor vehicles with at least four wheels designed and constructed for the carriage of passengers					
N	Motor vehicles with at least four wheels designed and constructed for the carriage of goods					
O	Trailers (Including semi-trailers)					
Note : Same color indicates that the vehicle shall full fill the requirements of previous category unless otherwise specified separately						

Table 1-1: Categories of Vehicles (2) (3)

1.3 Problem Definition

The automotive industry is one of the major consumers of resources. Every year end-of life vehicles in Europe generates 8 to 9 million tons of waste, to an extent which should be handled properly [(4)]. The automotive waste contains valuable raw materials that are not recovered at the moment because there are no available technologies for treatment of the shredder residue. Each year raw material costs are increasing due to the raw material shortage. Hence design for recycle is required in order to be able to recover these valuable raw materials as well as new technologies for sorting and recycling. Besides new applications for renewable materials are special interests in automotive engineering.

Due to global warming and pollution, thinking of product life cycle is increasing in the automotive industry. Electric vehicles are a promising alternative to fossil fueled vehicles. Considering the end-of life electric vehicles containing a lot of electric and electronic equipment, need to be recycled properly in order to avoid valuable materials to be lost in land filling. The increased demand for electric vehicles and batteries results in an increased demand for nickel, cobalt and manganese etc. At present the recycling of lithium is an expensive process compared to the mining of lithium. Besides, according to the latest numbers from the United States geological survey (USGS), the lithium industry is providing enough lithium to fuel the projected number of electric vehicles for the next ten years. But especially Europe doesn't have lithium resources that can be extracted by proven technologies. The overview of lithium, Nickel, Cobalt resources worldwide availability is shown in Figure 1-2. [(5)]

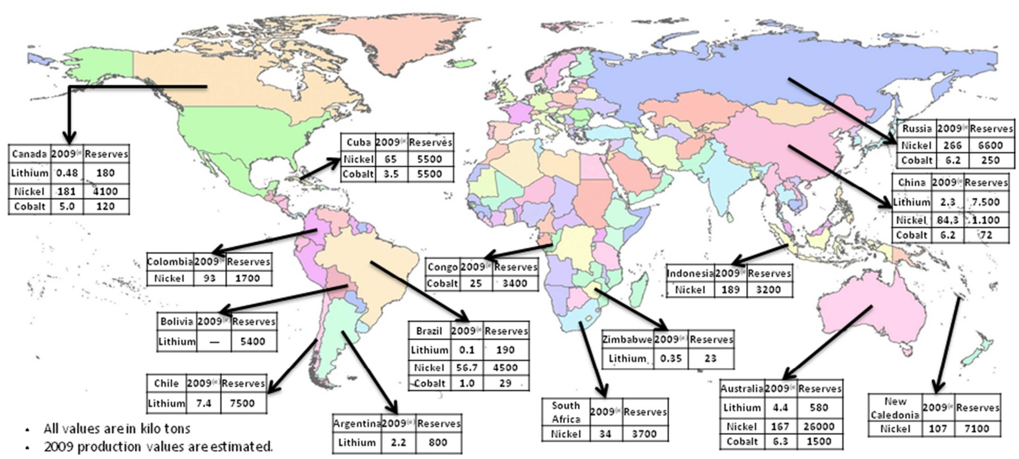


Figure 1-2 : Worldwide lithium, nickel and cobalt production and reserved resources (Source: USGS)

The major global lithium resources are located in limited regions in South America and Asia. So it is essential for European Union to have a recycling strategy to avoid lithium shortage in the future. In addition, there is currently a rapid change of the chemical composition of lithium-ion batteries and new technologies like lithium metal polymer batteries arise to improve the performance. Hence, there are no proven technologies to recycle lithium powered batteries economically. But regarding the fulfillment of recyclability rates for an electric vehicle, the recycling of the battery is essential as it is approximately one third of the weight of an electric vehicle in L7e segment.

Every year upcoming vehicles contain more electronics to obtain comfort, safety, entertainment and navigation. All electronics contains printed circuit boards that are shredded with the end-of life vehicle. Therefore, high valuable materials in printed circuit boards including copper, lead, silver, gold, platinum, and mercury remain in the ASR and are lost in landfilling as there are no economic and ecological proven treatment technologies are available. The increased use of recycled plastics is limited by worse mechanical and physical properties compared to virgin materials. At Present only 27% of the plastics used in European industries are recycled and only 8% from automotive waste [(6)]. The remaining residue is landfilled or energy recovered at blast furnace or cement works.

The main objective, according to Directive 2000/53/EC and 2005/64/EC automotive batters have to be dismantled and recycled before the vehicle is shredded. Batteries are considered as recyclable because of the proven recycling technologies for sulphur-acid starter batteries. But regarding lithium-ion powered batteries for electric vehicles, currently no proven recycling processes are available to justify the consideration of these batteries to be recyclable 100 %. Directive 2000/53/EC on end-of life vehicles (ELV Directive) is the prevention of waste from vehicles and the reuse, recycling and other forms of recovery of end-of life vehicles and their components to reduce the final disposal of waste. [(7)] Directive 2006/66/EC shall avoid the final disposal of batteries and accumulators by enhancing their collection and recycling. The Directive includes restrictions on the substances used in batteries and accumulators [(8)].

The ELV Directive initiated the reduction of the land filling rates by demanding recyclability and recoverability rates for the vehicles. But at the same time little concern arises on the subject of encouraging lightweight materials in the vehicle. In fact the recyclable mass of ferrous metals is reduced by lightweight materials resulting in a decreased recyclability rate of the complete vehicle. Thus light weighted construction increasing fuel efficiency of the vehicle during the life cycle is in contradiction to the targets of the ELV Directive. Therefore, OEMs face challenges to use a significantly higher amount of lightweight materials for new vehicles in the European market.

1.4 Objective

The primary objective of this thesis is to give an overview on the legal requirements for recycling in Europe & India, on the recycling oriented design in automotive engineering and to find the cost effective recycling solution for an electric vehicle. By investigating three different recycling scenarios and different available proven recycling technologies to achieve the legal recyclability rates for E-MILA Student.

The recycling scenarios are:

Scenario 1: ISO simplified – Energy recovery of non-metallic ASR
Scenario 2: PST VW-SiCon – Post-shredder recycling of non-metallic ASR
Scenario 3: PST Galloo – post-shredder recycling of non-metallic ASR

Another objective is the use of the highest feasible amount of recyclable materials and lightweight materials bearing in mind that a higher amount of especially lightweight materials like carbon fiber reinforced composites are not an indication for higher recyclability rates. In fact the use of such materials requires economical and efficient dismantling process of concerned parts in order to enable recycling activities.

2 Legal requirements for recycling

"*Even when laws have been written down, they ought not always to remain unaltered*." Aristotle (384 BC 322 BC), Politics.

Over the past years the automotive industry is one of the major contributors to urban pollution and waste. In three scenarios (EU-25, EU-15 and EU-10) the growth rate of end-of life vehicles is forecasted for Europe. Between years 2005 and 2015, the projected growth rate of the stock of cars is 1.7% p.a. for the EU-25 scenario. For the EU-15 scenario the annual growth rate is 1.5% whereas it is more than twice as high for the 10 new Member States with 3.3%. Considering these three scenarios, the projected ELV numbers till 2030 are shown in Figure 2-1. The projection model does not take export and import of used cars into account. In 2000, it was estimated that 8 to 9 million tons of waste from used cars were generated every year. ELV waste estimated to increase 14 to 17 million tons in 2015. (9)

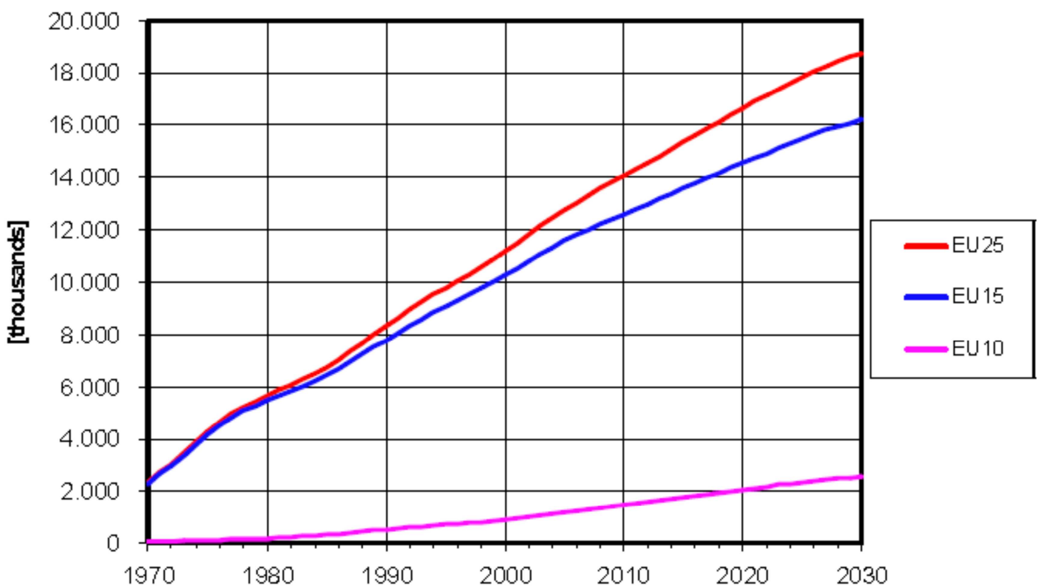


Figure 2-1: Projected development in the number of ELVs, 1970 - 2030 (9)

It is imperative to make sure that waste is treated properly to avoid pollution of the environment, to save natural resources and to protect human health. To protect the environment, a range of international and country specific legal requirements are available. Besides legislation industries and universities play a key role in the development and implementation of future innovative recycling solutions which will have to be compatible, not only economically but also socially and ecologically. The increasing world population causes increasing resources consumption worldwide. Thus recycling is essential to sustain the environment for the future generations. Recycling of products includes dealing with hazardous materials which might be harmful to the humans and the environment. In the past, end-of life vehicles were considered to be waste and the non-metallic materials were landfilled. But the hazardous materials damaged the fertility of the soil and polluted the ground water.

The Directive 2000/53/EC, introduced forms of economical instruments based on the producer responsibility principle. Innovation can be influenced when environmental policy has impact on very complex industrial subsystems.

Economic instrument	Externality addressed	Agents addressed	Markets affected	Potential impact on innovation	Possible side effects (negative)
Landfill tax	Land filled ASR	Shredders	ASR market	Technologies for energy/material recovery of ASR Dismantling organization and techniques	Illegal ASR dumping
Tax on virgin materials Subsidies on recycled material	(less) Land filled ASR through increased recycling	Material producers and recyclers Car makers	Primary material markets Secondary material markets	Material substitution New uses for recycled materials RRR techniques	Distortions in primary material markets Subsidized markets for recycled materials
Recycling credit/fee	ELVs abandoned in the environment Pollution in dismantling operations (less) Land filled ASR through increased recycling	Car buyers and ELV owners Dismantlers Recyclers	ELV market Secondary material markets Spare parts market	DFD and DFR Material substitution and innovation Dismantling organization and techniques	Subsidized markets for recycled materials Oversupply of recycled materials Cost shift to consumers
Free take-back	ELV abandoned in the environment Pollution in dismantling operations (less) Land filled ASR through increased recycling	ELV owners Dismantlers Car makers	ELV market Secondary material market Spare parts market	DFD and DFR Material substitution and innovation Dismantling organization and techniques	Cost shift to consumers
Deposit-refund system	ELV abandoned in the environment	Car buyers and ELV owners Dismantlers	ELV market	Dismantling organization and techniques	

Keys: DFD: design for dismantling; DFR: design for recycling ASR: automotive shredding residue

Table 2-1: Overview of the expected impact of economic instruments [(10)]

The illustrated framework in Table 2-1 summarizes the average knowledge of policy makers concerning the impacts of different economic instruments. In order to achieve determined policy targets on ELV recovery/recycling/reuse, interrelated sequences of single innovations in both upstream (car making) and downstream (car recycling/recovery) should take place. (10)

2.1 Legal requirements for recycling in Europe

In the year 2000, the European Union published Directive 2000/53/EC on end-of life vehicles to minimize the impact of end-of life vehicles on the environment. When it comes to the initiation of legislation, it is generally the European Council that sets the direction for EU policy. So, legislation is mandatory to protect the environment by using or encouraging clean and economical recycling process technologies. ELV regulation drove the automotive industry in a different perspective of vehicle design i.e. recycling oriented design. The design for recycling of new vehicles considering the cost minimization of recycling has turned out to be a crucial factor. Overview of ELV regulations are shown in Figure 2-2.

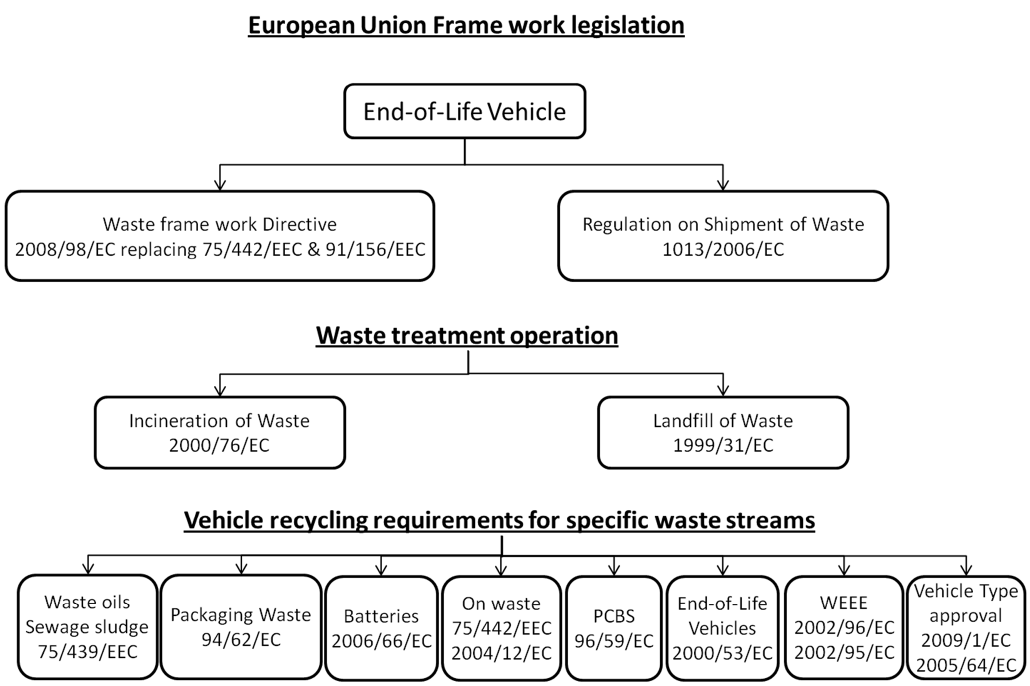


Figure 2-2: European Union frame work legislation for ELV

2.1.1 Directive 2000/53/EC on end-of life vehicles (7)

The intention of the ELV Directive is to reduce the end-of life vehicles impact on the environment, contributing to the protection, preservation, and improvement of the quality of the environment and energy conservation. ELV directive is very effective to decrease the landfilling of automotive waste. On the basis that approximately 25% of the weight of ELVs was land filled prior to the Directive, meeting the 85% target for reuse, recycling and recovery in

2006 will reduce the cost of landfill of ELVs by approximately 40%, while meeting the 95% target by 2015 will reduce landfill costs by 80%. [11]

The ELV Directive, a regulatory framework for vehicles was officially adopted by the European Parliament (EP) and EC in September 2000, and implemented on the 21 October 2000. The directive is based on the principle of manufacturer responsibility. Vehicle manufacturers are responsible for the reuse, recycling, recovery as well as for the recycling oriented design of their products.

The main objectives of this regulation are

- Prevention of waste from end-of life vehicles.
- Re-use, recycle and other forms of recovery of ELV's and their components and prohibition of cadmium, hexavalent chromium, lead and mercury in vehicle components.
- Design of recycling for components e.g. large plastic or non-ferrous components have to be dismantled if they cannot be separated after shredding of the vehicle to recycle them economically by proven technologies.
- Improvement in the environmental performance of all economic operators involved in life cycle of vehicles.
- Collection and treatment of ELVs at treatment facilities should meet strict environmental standards. These facilities are known as Authorized Treatment Facilities (ATFs).

In Figure 2-3, an overview of the requirements of ELV regulation are shown. Typically this regulation applies to all vehicles of category M1 and N1 according to Directive 70/156/EEC and three wheel vehicles according to Directive 92/61/EEC, irrespective of how the vehicle has been maintained and repaired. The vehicle manufacturers are responsibility for free take back and collection of end-of life vehicles. They are also responsible for installing networks of authorized treatment facilities. The heavy metals restriction according to the ELV regulation applies to vehicle materials and components and is detailed in Annex II of the Directive.

Figure 2-3: Overview of ELV regulation

2.1.2 Directives 2005/64/EC &2009/1/EC on the type-approval of vehicles (12)

Directive 2005/64/EC on the type approval of motor vehicles with regard to their reusability, recyclability and recoverability (RRR regulation) is part of the type-approval system established by the Framework Directive 70/156/EC. RRR regulation ensures that vehicles belonging to category M1 and N1 can be put on the European domestic market only if it can be verified that they are recyclable and/or reusable to a minimum of 85 % by mass, and recoverable and/or re-usable to a minimum of 95 % by mass. In future this regulation will extend to all categories of vehicles. It is therefore necessary to include environmental aspects in the development of vehicles of all categories.

The main objectives of this legislation are shown in Figure 2-4.

Figure 2-4: Requirements for car manufacturers for a type approval of vehicle according to Directive 2005/64/EC (Source: MAGNA STEYR)

Manufacturers are recommended to have a recycling strategy and recyclability calculations have to be in accordance with the standard ISO 22628:2002. Furthermore measures have to be taken, to prevent the reuse of certain component parts which have been removed from end-of life vehicles. A breakdown of all vehicle materials and their respective masses is required. Additionally the compliance of all materials with the heavy metals restriction has to be ensured and a listing of the dismantled parts including dismantling stage and the treatment process of the materials has to be fulfilled. (12) Maximum vehicles units produced in small series as shown in Table 2-2 are exempted from the RRR regulation.

Category	Units/year/country
M1	500
M2, M3	250
N1	500
N2, N3(1)	250
O1,O2	500
O3,O4	250
(1) For mobile cranes. 20 units.	

Table 2-2: Quantity of vehicles produced in small series per year per vehicle category (Source: Directive 70/156/EC)

2.1.3 Directive 2006/66/EC on waste batteries and waste accumulators (8)

The Battery Directive 2006/66/EC applies to all batteries and accumulators placed on the European market and aims to avoid the final disposal of batteries and accumulators by enhancing their collection and recycling. Directive 2006/66/EC also contains restrictions on the substances mercury, cadmium and lead used in batteries and accumulators. Lead-acid batteries have to meet a recyclability rate of 65% by weight, nickel-cadmium batteries have to meet 75% by weight and other waste batteries have to meet 50 % by weight. The Directive establishes an overall collection target for all spent portable batteries of 25% to be achieved by 2012 and 45% by to be achieved by 2016.

The main objectives of Directive 2006/66/EC are:

- Restrictions on the use of mercury (< 0.0005% by weight) in all batteries and restriction on the use of cadmium (< 0.0002% by weight) in portable batteries with certain exemptions.
- Collection requirements and collection targets for all batteries.
- Design for recycling and safe removal of batteries.
- High recycling efficiency for treatment process.
- Treatment and recycling of batteries by using best available technologies.
- Labeling requirements such as chemical symbols Hg, Pb or Cd, crossed-out wheel bin and capacity labeling for batteries.

There are a number of environmental concerns which arise when dealing with the waste management of batteries and accumulators. Major concerns are related to heavy metals contained in batteries. Mercury, lead and cadmium are the most dangerous substances in the battery waste stream. Lead batteries, Ni-Cd batteries and mercury containing batteries are classified as hazardous waste. Other metals commonly used in batteries, such as zinc, copper, manganese, lithium and nickel, may also add up to environmental hazards.

In addition to this, European Member States are required to promote research and encourage improvements in the environmental performance of batteries through their life-cycle and encourage the marketing of batteries which contain less polluting substances (in particular substitutes for mercury, cadmium and lead).The Batteries Directive allows Member States to exempt small producers from the financial producer responsibility obligations on the condition that this does not hamper the proper functioning of the battery collection and recycling schemes.

2.1.3.1 Collection of the batteries

The Batteries Directive gives importance to collection of spent batteries and accumulators (portable, industrial and automotive). Cost of the collection, treatment and recycling of waste batteries are in responsibility of the producer. Producers and users of industrial and automotive batteries may conclude agreements specifying alternative financial arrangements. Producers are also responsible for financing the costs of public information campaigns on the collection, treatment and recycling of waste portable batteries. Member States must make sure there is no double-charging of producers where batteries are collected under Directive 2000/53/EC.

2.1.3.2 Information to end user

Battery producers are responsible for cost of public information campaigns on collection, treatment and recycling of waste portable batteries and they must ensure that the public is informed.

Directive 2006/66/EC includes requirements to give end users the following information:

- The potential environmental and health effects of substances used in batteries.
- Batteries should not dispose as a solid municipal waste.
- Available collection and recycling schemes.
- Consumer’s responsibility in contributing to the recycling of waste batteries.
- The meaning of labels.

2.1.3.3 Export of waste batteries

When waste batteries are sent for recycling to another Member State or exported to outside the Community for recycling, they must strictly follow with the waste shipment laws as specified in Article 15 of the Batteries Directive. When waste batteries are exported outside the Community, Member States should ensure that these exported outside community batteries are going to recycle according to the conditions set by this Directive, including those on recycling efficiencies by 2011.

2.2 Legal requirements for recycling in India

Indian Automotive industry is one of the most important drivers of India's economic growth. It has shown great resilience during the recent global economic crisis. Due to its rapid growth the Government of India is planning to have a specialized committee to administrate the industry towards sustainable growth.

2.2.1 Indian Automotive Industry

The Indian automotive industry is growing rapidly and it is the seventh largest automotive industry in the world with an annual production of over 11 million vehicles in the year 2009. Vehicle sales in India are expected to be 31 per cent in 2010, to 2.7 million units and expected to grow in future. Only 14 out of every 1000 Indians own a car or utility vehicle, and the figure is much lower in the countryside. (13) Therefore, there is a huge potential to grow in the future. For the Indian financial year 2008-09 and 2009-10, various vehicle sales are illustrated in the Figure 2-5.

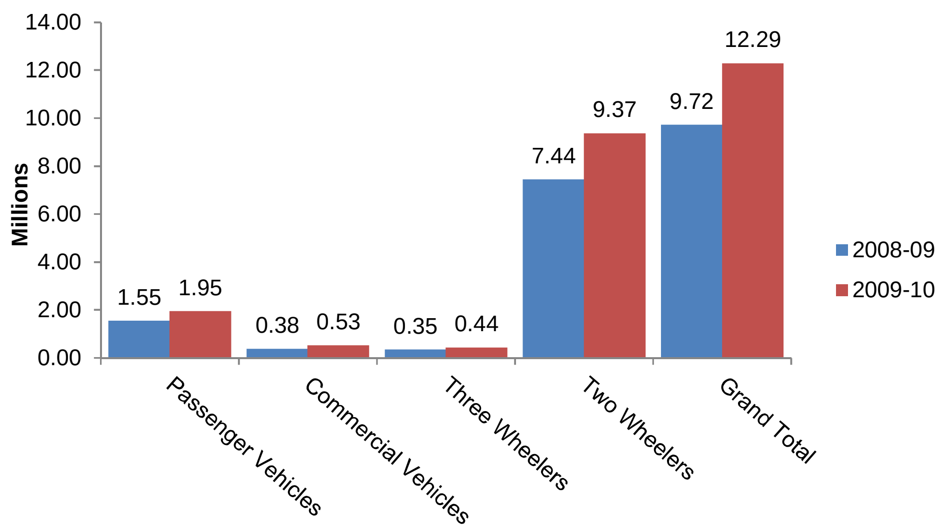


Figure 2-5: Vehicle sales in India 2008-2010 (Source: SIAM India)

2.2.2 Indian Automotive Regulatory Framework (14)

The Indian automotive regulatory framework is illustrated in Figure 2-6. The automotive Industry Standards Committee (AISC) was set up under Central Motor Vehicles Rules -Technical Standing Committee (CMVR - TSC) by the Ministry of Road Transport & Highways, (Dept. of Road Transport & Highways) (MoRT&H (DoRT&H)) in the year 1997 to review the safety in the design, construction, operation and maintenance of motor vehicles. The National Standards for Automotive Industry are prepared by the Bureau of

Indian Standards (BIS). The standards formulated by AISC are also converted into Indian Standards by BIS. The standards formulated by both BIS and AISC are considered by CMVR-TSC for implementation.

Figure 2-6: Indian Automotive Industry regulatory framework (Source: SIAM India)

India has committed to participate in the formulation of Global Technical Regulations. It is important that views of the Indian automotive industry as well as test agencies are transmitted with authenticated data to the respective groups under which the discussions take place. To accomplish this objective, six groups are formulated, which work on various standards.

- GRPE Working Party on Pollution and Energy.
- GRSG Working Party on General Safety Provisions.
- GRRF Working Party on Brakes and Running Gear.
- GRE Working Party on Lighting and Light-Signaling.
- GRB Working Party on Noise.
- GRSP Working Party on Passive Safety.

2.2.3 Vehicle recycling regulations

Each year millions of vehicles are put on to the Indian market, it is inevitable to think about the end-of life of these vehicles. Currently the Indian Government is preparing a roadmap to setup the regulations for the end-of life vehicles similar to the European ELV Directive. Fleet modernization is important for reducing the pollution load from the automotive industry. There is a need to deal with this issues and challenges of recycling in India and prepare a future plan. In order to ensure that NATRiP (National Automotive Testing and R&D Infrastructure Project) and SIAM (Society of Indian Automobile Manufacturers) have recently taken first step and established a pilot automotive recycling plant at Sicot industrial estate on Chennai outskirts. This plant is expected to be commissioned in the first quarter of 2011 [15]. Since, there are some initiations that Government is going to set up ELV regulations in the near future.

3 Design for recycling in the automotive industry

Design for recycling has become a fundamental part of automotive product design and development. Raw materials shortages and strict regulations regarding land filling of materials trigger new research on the development of new innovative recycling processes. There are proven recycling technologies available for the automotive industry to recycle end-of life vehicles. Main barriers for the recycling of vehicles are the variety of different materials and the difficult to separate the material mix after the shredding of the vehicle. Besides, the majority of end-of life vehicles in Europe are exported to Africa and Asia instead of being treated properly in Europe. In automotive product development process, the improvement of vehicle recyclability and the integration of environmental aspects are an integral part of strategic preliminary and series development. An overview of activities for integration of environmental aspects in automotive development is shown in Figure 3-1.

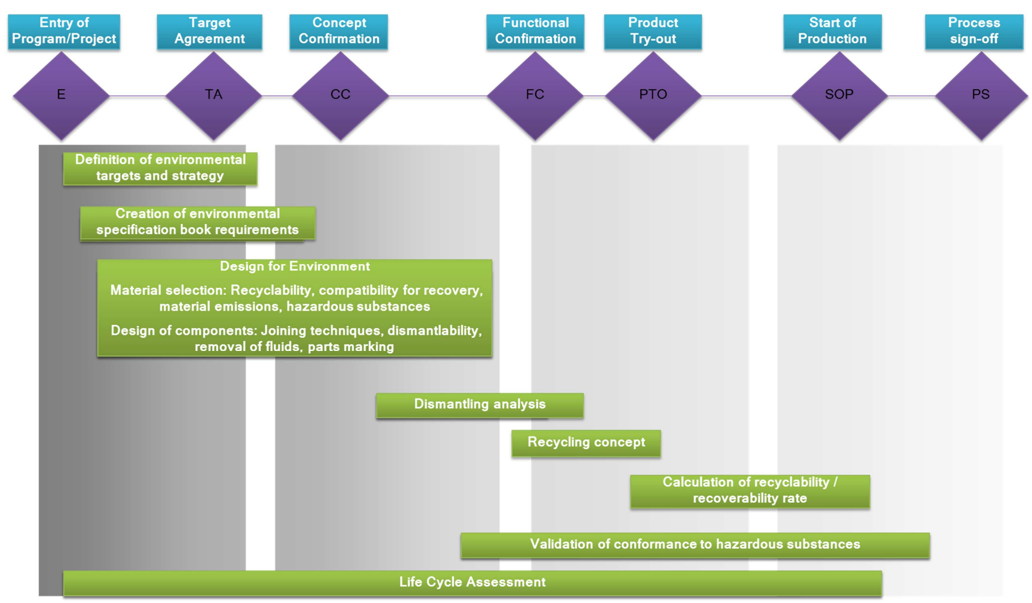


Figure 3-1: Integration of environmental aspects in automotive design (Source: MAGNA STEYR)

The product designer decides about the major environmental impacts of his component by selecting materials, defining joining techniques and designing the product. Therefore the design for recycling is essential for the development of more environmentally compatible products.

3.1 Product development process [16]

The conventional way of product development process is sequential in which the product goes sequentially through various processes like concept, design, validation, testing, production, marketing and sales. Modern product development processes are simultaneous rather sequential. In general, the development can be categorized into three phases, which are strategic development, preliminary development, and mass-production development. These phases are used as structuring levels for the definition of recycling relevant working tasks. Figure 3-2 shows the primary recycling characteristics to be taken into account in theses phases.

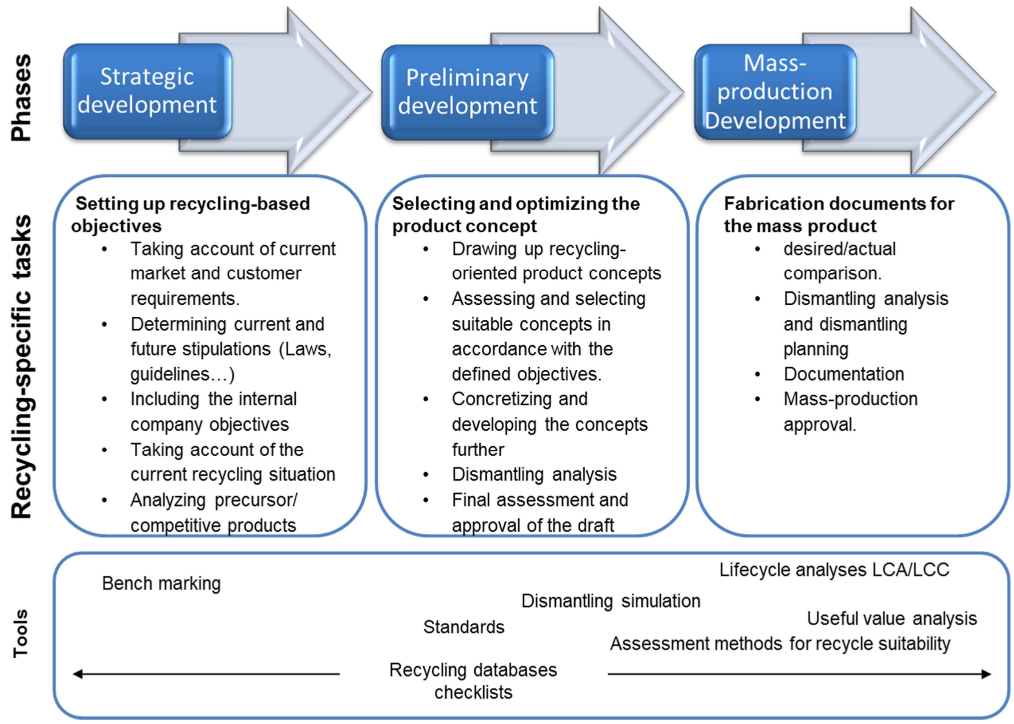


Figure 3-2: Product development process stages (Source: Standard VDI2243)

3.1.1 Strategic development

In this phase, every vehicle manufacturer should develop a specific recycling strategy including recycling relevant product requirements, such as environmental compatibility and recyclability and recycling-based development objectives, for example within the requirements specification or by means of working standards, guidelines and so on. Then these stipulations must be transferred into the requirements list. If, however, no appropriate statements are formulated, then internal company objectives from a recycling point of view must be determined and appropriate recycling requirements for the product development must be derived (competitive advantages, image, environmental aims, management targets, etc.).

3.1.2 Preliminary development

In the preliminary development phase, the decision taken about the recyclability of a product have a great influence, since the fundamental product structure contains material groups, assembly level and relation between the components. So it is therefore necessary to perform qualitative and quantitative assessments of the recyclability and also considerations of the potential risks for validating the concept. Concept development should consider the reachability of the objectives for product development, on the one hand, and the requirements for the suppliers on the other hand. The developed concepts are firmed up further under the boundary conditions of the defined recycling requirements. The geometric design and the selection of materials and fabrication methods finally define the important recycling characteristics of the product. Efficient design of a product must be realized at the lowest possible expenditure and the maximum possible recyclability. To achieve the recycling objectives, it is necessary to consider the design, joining technique and material structure of the product.

3.1.3 Mass-product development

In this phase, the recycling of the product can be influenced by expenditure in terms of time and costs. The cost of the recycling depends on the design and material selection of the product. It is required to describe the measures for the subsequent implementation of the predicted aim of the recycling based development. This documentation must be designed to be easy to apply during subsequent use in service and recycling. The complete environmental product documentation should include the following statements:

- Description of used materials (weight, composition).
- Description of used substances and their concentrations.
- Identification of components (position, accessibility), with high environmental impacts identified via Life Cycle Assessment.
- Recycling concepts including product description, dismantlability, available material treatment and recycling technologies.
- Calculation of product recyclability and recoverability.
- Economic evaluation of the recycling processes, including dismantling, separation, processing and logistics.

3.2 Recycling-oriented design [16]

Recycling oriented automotive design, in principle should provide the cost effective and sustainable way to reduce the impact of ELV treatment on the environment. It increases the recyclability rate of materials or components by selection of recyclable materials, easily detachable connecting elements and by appropriate marking of the materials on the components. It provides competitive advantage to the manufacturer in terms of cost and time to fulfill the legal requirements and also in terms of image. Therefore it has become an essential tool for the vehicle manufacturers. Recycling oriented design is an approach, integrating environmental criteria in product development as part of the corporate strategy.

3.2.1 Requirements and conflicts

All the requirements for the product like technology, functionality, economy, environment and ecology should be considered by the product designer. It is product designer responsibility to develop environmentally compatible products that meet not only economical and technical targets but also sociological and ecological requirements. Successful products therefore require integrated intelligent approaches to solutions and efficient conflict management. Implementing the recycling requirements as an integral constituent of an overall ecological product optimization process requires a target oriented procedure in the entire product generation process show in Figure 3-3.

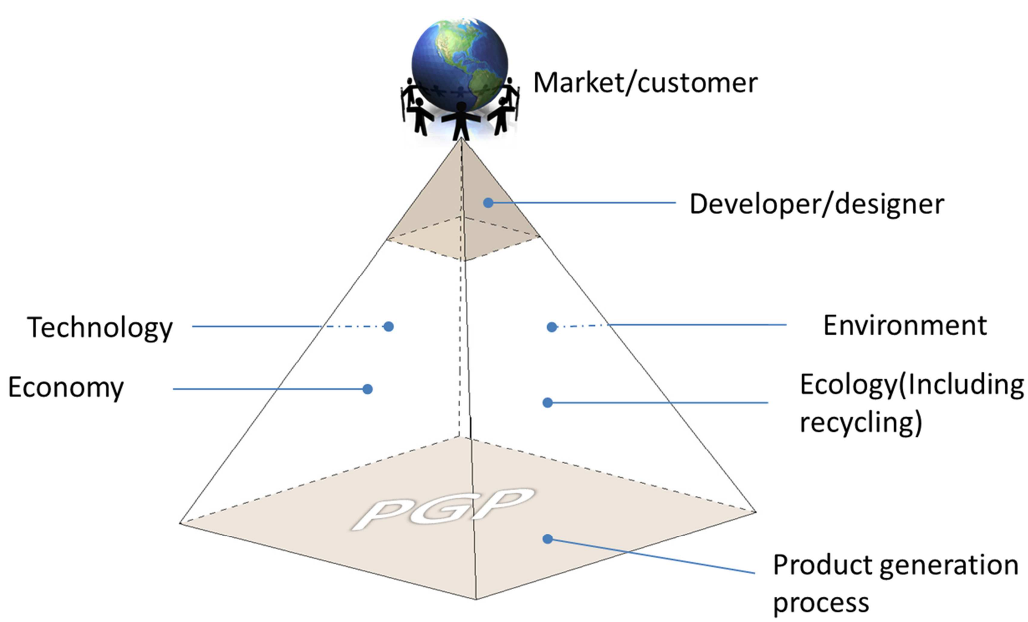


Figure 3-3: The developer in the field covered by requirements (Source: Standard VDI 2243)

3.2.2 Procedure and prioritization

At the end-of the life of technical products, it depends on specific conditions if the product can be reused, recycled or disposed. On the basis of the maximum ecological and economic creation of value, the result is the recycling cascade depicted in Figure 3-4.
In this case, the ecological premises are:

- Efficient use of all resources (raw materials, energy etc.).
- Reuse and recycling of materials and reducing of emissions.

In Figure 3-4 a staged procedure for the assessment and selection of the most economic and ecologically effective treatment of an end-of life vehicle is shown. By considering company, local, regional and national conditions, staged and product-specific processing can be carried out by using recycling criteria which have to be checked at defined milestones during product development.

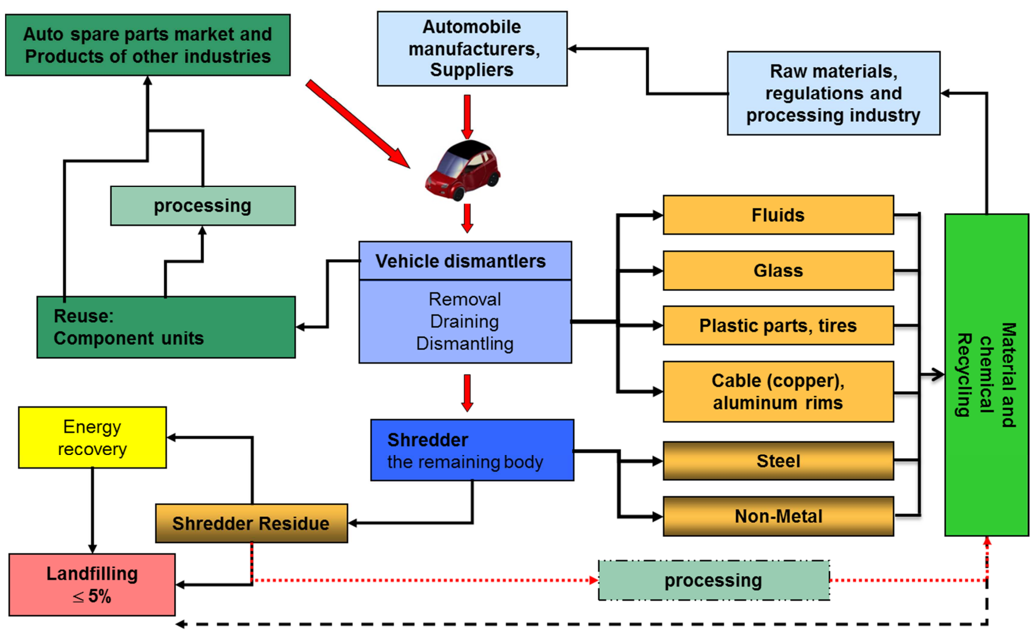


Figure 3-4: Recycling cascade of End-of life Vehicle (Source: MAGNA STEYR)

The selection of materials greatly influences the recyclability rate. Thus, environmental friendliness has become an important criterion for materials selection for that material should have below properties.

- Labeling of materials.
- Recyclable materials and its compounds.
- Eliminating hazardous materials.

- Eliminating recycling-critical materials, which disrupt specific recycling processes (e.g. transmission oil in the shredder process).

A rough checklist for recycling-oriented product development is shown in Table 3-1

Technical recycling criteria	**Assessment**	**Potential optimization by**
Suitability for materials recycling	recyclable, identical properties	no optimization necessary
	recyclable, inferior properties	test use of higher-grade materials
	not recyclable, disposal necessary	use recyclable materials
Recycling compatibility	compatible, identical properties	no optimization necessary
	compatible, inferior properties	possibly optimized material variety
	incompatible	use compatible materials
Identifiability	clear, simple, machine-readable	no optimization necessary
	readily separable, no marking	at least provide marking
	impossible, no marking	avoid, provide marking
Recycling-critерical materials	not present	no optimization necessary
	present, marked, readily separable	at least provide marking
	present, inseparable, disposal necessary	avoid, provide marking and disassembly
Pollutants and hazardous substances	not present	no optimization necessary
	present, marked, readily separable	ensure long-term good legibility
	present, inseparable, disposal necessary	avoid, provide marking and disassembly
Recognizability	clear, visible	no optimization necessary
	not visible, but indication	provide marking
	not visible, but indication	provide indication and marking
Accessibility	directly accessible	no optimization necessary
	indirectly accessible	possible improve extent of disassembly
	inaccessible	test change to axial accessibility
Types of connection	detachable nondestructively	no optimization necessary

	partially destructive, only connection	use nondestructive connection
	destructive, including component damage	use detachable connections
Variety of connections	single/few, uniform type	no optimization necessary
	functionally-specific variety, standardized	test possible reduction
	unmanageably many	reduce the number
Disassembly time	low	no optimization necessary
	considerable time consumption	test possible reduction
	very high, unacceptable	improve accessibility, use modular construction
Recycling processes	optimum process used	no optimization necessary
	complex process steps required	test compatibilities
	no process available for materials	change materials, standardize

Table 3-1: Rough checklist relating to recycling-optimized product development (Source: Standard VDI 2243)

In accordance with a range of designs, materials, products and processes, the rough checklist enables optimization of the product development by assessing the technical criteria and defining appropriate corrective actions. In the first column of Table 3-1, the technical recycling criteria explain the technical recycling-oriented related issues. The second column defines the assessment details and the third column shows the potential for optimization.

3.3 Design Recommendation [16]

The overview of the important aspects for the three design columns are explained in Figure 3-5. The design columns are “construction structure”, “materials” and “connections”. These columns are assigned to the different product detailing levels. This illustration is intended to make it clear that, for each detailing level, various recycling criteria from the three design areas have to be taken into account for the design recommendations.

General	Recycling concept	Detachability	Recyclability
Product specific	Modular Compatibility for use Construction	Type and range of connections	
Component specific	Accessibility	Dismantling level and time	Multiplicity of materials
Material specific	Separability compatibility	Dismantling time	Material selection
Level and degree of detailing	Overall structure	Connections	Materials

Figure 3-5: Allocation of product detailing level to the respective recycling-relevant design aspects (Source: Standard VDI-2243)

3.3.1 Design for disassembly (DFD) using TRIZ [17]

Disassembly is a manual process of removing components from an end-of life vehicle. Therefore the process is cost and time intensive and innovation is required to minimize the costs. Design for disassembly (DFD) is a key element to achieve the recycling targets and minimize the recycling costs. Recycling industries are researching on how to design products for easier disassembly. It's an innovative approach, the TRIZ methodology is used to develop the design of disassembly. "TRIZ" is the acronym for Theory of Inventive Problem Solving (TIPS in English). TRIZ was developed by Genrich Altshuller and his colleagues in the former USSR starting in 1946, and is now being developed and practiced throughout the world.

Advantages of DFD by using TRIZ are:

- TRIZ tools help to generate the ideas to make disassembly easier without losing the joint functionality.
- The level of concept required to produce ideas using the 40 inventive principles is higher than the level required to use the effects or separation principles.

TRIZ tools can be divided into analytical and knowledge based tools. They look for the correct approach to the problem, and give useful ideas to solve the problem. These tools are:

- Ideality.
- Effects.
- Principles (contradictions).
- Evolution of the Systems.
- Standards (S-fields transformations).

- Algorithm of Inventive Problem Solving (ARIZ).

The TRIZ methodology consists of four phases:

- Definition of the DFD parameter.
- Generation of ideas with TRIZ.
- Evaluation of ideas.
- Innovation in DFD parameter.

3.3.1.1 Definition of the DFD parameter

The objective of the DFD is to ensure easy and fast disassembly. To make this process easier the inverse function has to be considered. The joining components and the connecting elements assure the joining force. First step of the DFD is to analyze the type of joint and then next step would be to generate ideas using the ideality principle, the effects (if we know what to do but we do not know how) and the principles (when we do not know what to do but a contradiction is defined).

3.3.1.2 Generation of ideas with TRIZ

Ideas are generated with the use of three TRIZ tools: ideality, effects and contradictions.

Ideality

The ideal system requires no joining element because the connecting element is provided by the parts themselves. To find solutions for the problem of the ideal system, the designer's knowledge and inventive principles are required

Effects

Most of the solutions are based on the advantages provided by a known effect. These effects may be physical, chemical or geometrical.

Contradictions

By analyzing the previous joining element example, by means of the technical and physical contradictions ideas can be generated.

3.3.1.3 Evaluation of ideas

Table 3-2 shows some ideas generated by using the TRIZ methodology. It offers two different ideas which are traditional and innovative ideas. The traditional ideas are based on designer knowledge and the innovative ideas are to break the psychological inertia, which are beyond the knowledge of the designer.

IDEAS	Disassembly
To heat or to cool the connected parts	Expansion of parts on hot or shrinking
	Heat adhesion
To deform a body	To deform a body to disassemble
	Shape-memory material (it is activated with electricity, etc.)
Magnetic force joint	Electro rheological fluids, when applying magnetic or electric field increases its viscosity
	A magnetic field moves a part that makes the closing of the joint
Electric force joint	Attraction between two bodies
	The voltage moves a part. E.g. it closes the door of the washing machine
Joint by adhesion	Adhesives (chemical joint), glues
	Polymeric Velcro, metallic Velcro
Pneumatic or hydraulic force	An element expands and it exerts the pressure of joint
Fixation by solidification of a substance	A liquid passes to solid. E.g. solid in ambient temperature and liquid in other temperatures
The parts to join carry out themselves the joint	In this case, the most obvious solutions would be the ones by force fits, or by shape, etc.

Table 3-2: Example of ideas achieved by using TRIZ methodology

3.3.1.4 Evolution of type of joint parameter

This evolution corresponded with other ones, in which the evolution passes through solid, liquid and gas states of substances and other fields. Possible type of evolution is based on the segmentation of the element which assists the joint. However, Table 3-2 shows that some of the combinations are possible.

Dismantling is not the only step of automotive recycling. Before the dismantling of components, the end-of life vehicles is pretreated in a depollution rig. The complete procedure of automotive recycling is described in chapter 4.

4 Process sequence of automotive recycling in Europe

The four steps of the automotive recycling process are pre-treatment, dismantling, shredding of the vehicle including metal separation and the treatment of the non-metallic shredder residue. According to ELV regulation end-of life vehicles have to be collected and treated at authorized treatment facilities. Only these facilities can issue a certificate of destruction (CoD), which is required for deregistration of the vehicle. After the certification, the depollution of the vehicles in the pretreatment step begins with the removal of battery and the dismantling or neutralization of pyrotechnic devices such as airbags are neutralized or dismantled. After that vehicles are placed on a depollution rig for draining of all the liquids. These fluids are treated accordingly by specialist waste management companies. During the dismantling stage, vehicle components are dismantled for reuse or recycled by proven technologies depending on the material. After the dismantling of target parts for recycling, the remaining vehicle goes to the shredding facility for further processing. The vehicle is shredded and sorted. Processing technologies are available to separate the ferrous, non-ferrous metals and defined plastics that can be recycled at specialized treatment facilities.

The recycling process sequence in current automotive recycling industry is shown Figure 4-1.

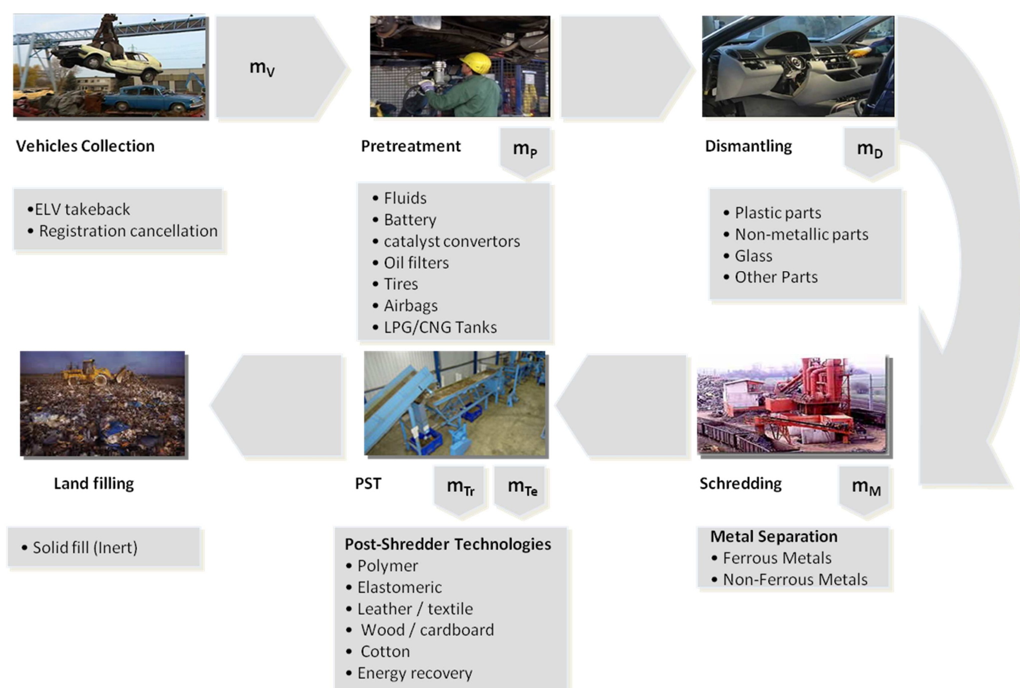


Figure 4-1: Recycling process sequence for end-of life vehicles (Source: MAGNA STEYR)

4.1 Pretreatment

Pretreatment is one of the most important and the first step in automotive recycling. In this step, all the fluids in the vehicle are removed in a depollution station by using different draining tools. These fluids are reused or recycled separately. Automotive fluids are very dangerous for human health and environment and can damage the fertility of the land. In the process of pretreatment, the following fluids can be recovered vehicle after end-of life. (18)

- Brake fluid and clutch fluid.
- Windscreen washer fluid.
- Power steering oil
- Engine oil
- Transmission/gearbox oil.
- Battery.
- Hydraulic suspension fluid.
- Tires.
- Coolant.
- Catalyst.
- Air-conditioning refrigerant.
- Fuel tanks (e.g. LPG tank, CNG tank).
- Airbags neutralization.
- Identify and remove items containing mercury.
- Identify and remove other hazardous parts.

4.2 Dismantling

ELV Directive requires the dismantling of large plastic components and non-ferrous metal components containing copper, aluminum and manganese if these materials are not segregated in the shredding process that they can be effectively recycled as materials. At present this is a major problem because, the processing of the non-metallic shredder residue is technologically challenging and the disassembling of these components is costly. Manual disassembly is expensive in terms of labor cost and time. The optimization of disassembly is achieved by minimizing costs and time. The design of new products must incorporate the feasibility of fast and easy disassembly. The fundamental requirement of dismantling is that the value of the materials must be greater than the costs of disassembling. However the normal disassembly is very expensive due to high labor costs in Europe. Therefore, it is necessary to check the economic feasibility of disassembly. A decision factor can be determined to evaluate the economic feasibility for disassembly of a component. The economic feasibility also depends on the facility location, dismantling time and distance and type of transportation to the recycling plant.

4.3 Metal Separation in Automotive Shredder

An automotive shredder is a massive and capital-intensive, 3,000–8,000 bhp hammer mill that shreds end-of life vehicles and other metal-containing scrap into mostly fist-size chunks to separate metals from other materials. Dry shredding is used in most cases. The output from the shredder is a mixed material fraction which is divided by air separation into a heavy and light fraction. The operations of processing may be different from site to site but the core process involves air classification followed by stages of magnetic separation to recover the ferrous materials. Trommels are used to remove particles smaller than 16 mm followed by the stages of density and eddy current separation to recover non-ferrous metals. The discarded materials of the heavy and light fraction is called automotive shredder residue (ASR). (19)

4.3.1 Automotive Shredder Residue

Several stages of separation and cleaning are required for the recovery of materials from ASR including concentration of the targeted material into a more manageable fraction, separation of materials and cleaning of the recovered materials to remove impurities. The ASR contains 15 to 20 % by mass of the total vehicle materials. ASR is composed of plastics, rubber, foam, residual metal pieces, paper, fabric, glass, sand, and dirt. Hence, it is a very complex heterogeneous mixture of combined materials that is tremendously difficult to separate and handle. It contains materials like moisture, wood, metals, glass, sand, dirt, automotive fluids, plastics, foam, rubber, fabrics, fibers, and others that are not compatible for recovery. In addition to these materials ASR also contains considerable amount of heavy metals, PCBs and fire retardants. (20)

Problems that are hindering the recovery and recycling of the ASR are:

- Location of the facility.
- Facility utilization ration.
- Distance and type of transportation.
- Lack of a cost-effective technology to separate these materials material recycling.
- Lack of markets for recycled materials at their fair market value.
- Not enough quantities that can be generated at a given site to validate a profitable business case.

By treating 130 tons of residues by Argonne's pilot plant, a detailed material detailed breakdown of the automotive shredder residue is shown in Table 4-1. (21)

Component or Parameter	Shredder Residue	Oversized Heavies	Oversized Foam Rich	Fines[a]	Ferrous Rich	Non-Ferrous Rich	Lights	Polymer Concentrate
Weight (Kg)	18181.8	976.4	343.6	8018.2	298.2	667.3	894.5	4565.5
PP	488.6	0.0	0.0	0.0	7.7	15.0	58.6	407.7
PP(filled)	183.2	0.0	0.0	0.0	0.0	0.0	4.1	178.6
ABS	346.8	0.0	0.0	0.0	2.3	4.1	5.9	335.0
PE	427.7	0.0	0.0	0.0	4.1	8.2	38.6	377.3
HIPS	118.6	0.0	0.0	0.0	1.8	3.6	6.8	106.4
Nylon	172.3	0.0	0.0	0.0	1.8	4.1	8.6	157.7
PVC	232.7	0.0	0.0	0.0	0.0	0.0	0.0	232.3
PPO	63.2	0.0	0.0	0.0	0.0	0.0	1.8	61.4
PC-ABS	68.6	0.0	0.0	0.0	0.0	0.0	0.5	68.2
PC	96.4	0.0	0.0	0.0	0.0	0.0	5.5	90.9
Other Plastics	271.4	0.0	0.0	0.0	0.5	0.0	7.7	263.2
Rubber	2047.7	9.1	0.0	0.0	2.7	78.2	27.7	1930.0
PU	124.1	1.4	0.0	0.0	0.5	10.5	4.1	107.7
Wood	108.6	0.0	0.0	0.0	0.0	0.0	0.0	108.6
Metals	1323.2	507.7	0.0	0.0	268.2	433.6	0.0	113.2
Foam, fiber and others	9690.9	458.2	343.6	8018.2	8.6	109.5	725.9	26.8
Moisture	2418.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**18181.8**	**976.4**	**343.6**	**8018.2**	**298.2**	**667.3**	**894.5**	**4565.5**

[a]Fines are material smaller than 6.35 mm size and contain some polymers and metals

Table 4-1: Material composition of an average ASR by mechanical separation (Source: Argonne, 2009)

4.3.2 Separation of Materials from Shredder Residue

The materials of the ASR can be separated due to their different material properties. These properties include physical (size, shape, color, porosity, density, and brittleness), chemical (solubility, hydrophobicity, hydrophilicity, and reactivity), magnetic and electric (resistivity and dielectric constant) properties. Similar properties of different materials make the separation process very difficult to control. Especially the separation of materials for material recycling is very complex and challenging. (19) Additionally many new materials have been developed to replace conventional materials. Due to continuing changes in the material composition of the ASR the process for separation becomes more complicate. In order to be able to fulfill the recyclability and recoverability rates according to ELV directive, treatment of post-shredder materials is necessary. There are several proven post-shredder recycling technologies available for the ASR treatment. They are based on mechanical sorting of the ASR into different fractions that can be recycled or energy recovered. Over the last decade, many companies developed post-shredder technologies with tremendous improvements in separating and recovering materials from shredder residue to cope up with the ELV regulation.

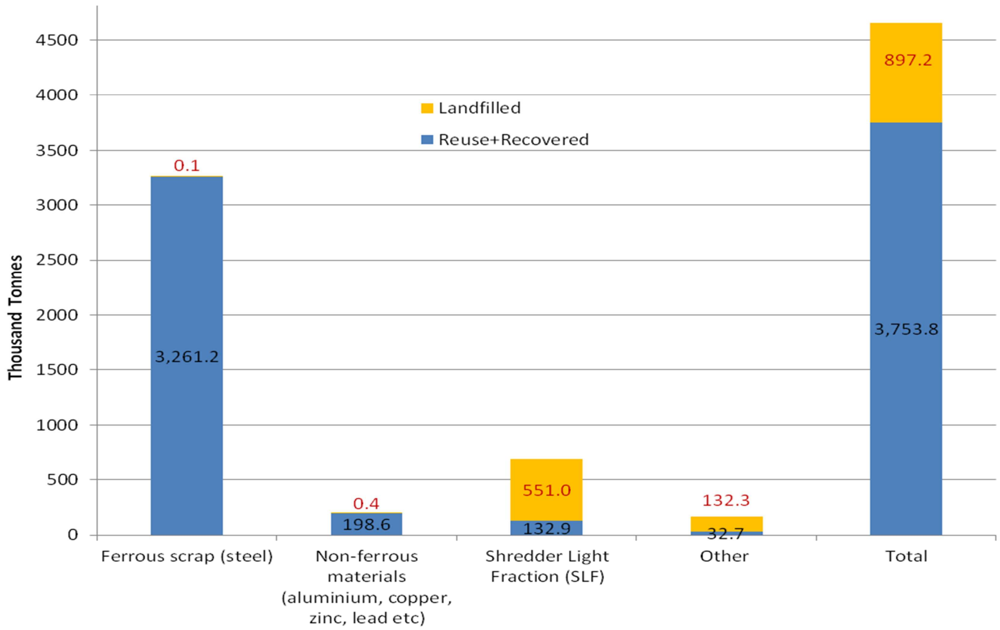


Figure 4-2: Materials from shredding of end-of life vehicles arising in the country and treated within the country (tons) (Source: Eurostat)

In Figure 4-2, the total ASR material fractions of end-of life vehicles treated within the European Union are given. (22) These materials are treated by the various post-shredder technologies (PST). In Table 4-2 the proven post-shredder technologies are described. Some of the technologies are already operating at industrial scale (Galloo, Sult, R-Plus, Twin-Rec) and some of the processes (VW-SiCon, TwinRec, Reshment) are technologies which are licensed to operators (23).

In this study the selection of the scenarios is based on their economic and ecological performance. The Galloo scenario is selected based on the total treatment of the shredder residue. Galloo group recycles 1,400,000 tons of ferrous metals, 80,000 tons of non-ferrous metals, 20,000 tons of plastics and 150,000 tons of shredder residues per annum.

RRR= Reuse, Recyclability and Recoverability Rate, RR= Reuse and Recyclability Rate

Name of Technology /Developer	Type of Technology	Level of Technology Development	Approximate Outputs from Process	Overall Rate of RRR (%)	Recycling Rate RR (%)	Indicative Gate Fee (euro per ton of ASR)
VW – SiCon	Mechanical separation	Over 200.000 tons/year of shredder residues are treated in *Europe*. Expected capacity by mid-2011 is 400.000 tons/year	Shredder granules 36%, shredder fibres 31%, metals 8%, wastes 26%	74	74	20 – 50
Galloo	Mechanical Separation	17 plants in Belgium, 19 in France and 1 in the Netherlands	Recycled plastics 9%, metals 30%, refuse derived fuel 13%, wastes 48%	52	39	25
Sult	Mechanical separation	Operating plant in Japan	Organic (plastic) 50%, minerals 20%, metals 10%, water 20%	100	80	100
R-Plus	Mechanical separation	Operating plants	Organic fraction 60%, metals 5%, minerals 35%	100	100	90
Citron	Thermal treatment – oxyreducer	1 trial plant (130,000 ton, 12,000 ASR). Plans for a 500,000 ton (120,000 ASR) plant.	Current – Ca Fe concentrate 45%, zinc concentrate 4.3%, mercury 0.7%, wastes 50% Plan – Ca Fe concentrate 45%, Zinc concentrate 4.3%, mercury 0.7%, recovery 50%	50 100	50 50	100 – 200 (excluding energy sales)
TwinRec	Thermal treatment - gasifier	Operating plants in Japan	Metals 8%, glass granulate 25%, recovery 52%, wastes up to 15%	85	33	120 – 200
SVZ Schwarze Pumpe	Thermal treatment - gasifier	Industrial trial plant	Synthetic gas 75%, metals 8%, wastes 17%	87	8	Not available
Reshment	Mechanical separation & thermal treatment	No pilot or trial plants	Not available	Not availabl e	Not available	75 – 140

Table 4-2: Overview of Post-shredder Technologies (Source: Annex III, EC) [24]

In total 1,650,000 tons of materials are treated by Galloo recycling group which is approximately 35.4 % and VW-SiCon is treating approximately 17.2 % of total material fractions of ELVs treated in the European Union. (25) (26)

VW-SiCon scenario selected based on the economical gate fee for treating the waste as compared to other PSTs shown in Table 4-2. Gate fee is the charge to waste producers for treatment of the waste stream. The fee is determined by the treatment costs less income from sales of materials or energy. Transport costs are borne by the waste producer.

4.4 Treatment of Non-metallic Shredder Residue

Over the past decades treatment of non-metallic shredder has become greater interest. Many Post-Shredder technologies are developed to treat the non-metallic materials economically. The detailed processes of PST VW-SiCon and PST Galloo are explained below.

4.4.1 The Volkswagen-SiCon Recycling process (26)

In corporation with Volkswagen AG, SiCon has developed a process for treating ELVs. This process has been developed to meet the legal requirements of ELV under the pre-requisites of sustainable development. It combines economic and ecological advantages compared to cost-intensive dismantling and subsequent mechanical recycling of parts. Today more than 200,000 tons of shredder residues are treated per year in Europe. By mid-2011 the annual ELV treatment capacity of the VW-SiCon process will increase to 400,000 tons.

In VW-SiCon process, the first step of the recovery cycle is to hand in the scrap vehicle to a certified pretreatment operation. The vehicle is placed in a depollution rig to remove catalysts, oil filters and batteries. The airbags are fired for safety reasons. The tires are dismantled and all operating fluids (engine oil, gear box oil, power steering, shock absorber oil, air conditioning refrigerants, brake and coolant fluids) are removed. The next step of the process is the dismantling step, in which components may be dismantled and sold directly as used spare parts. The glass of windscreen, side windows and rear windows are also removed. Depending on the economic conditions of the dismantlability and the demand on the market for recyclates, plastic parts are dismantled for material recycling. The remaining vehicle is crushed and shredded in to pieces to separate and recycle the metallic materials. (27)

The remaining non-metallic shredder residue is further treated by new technologies to achieve the high recovery rate of at least 95%. The four major output fractions of VW-SiCon technology for the shredding residue are shredder-granulates, shredder-fibers, shredder-sand and PVC. Shredder granulate is a plastic fraction with low chlorine and metal content which is feedstock recycled or energy recovered in the blast furnace. Shredder fibers are a mixture of textile fibers and foam, which can be used as a dewatering agent instead of coal dust. Shredder sand contains glass, fine iron particles, rust, fine copper wires, dust containing lead, zinc and lacquer particles. These particles can be used as reducing agents in the non-ferrous metal industry. The PVC fraction can be recycled in the Vinyloop process developed by Solvay. The VW-SiCon process involves multistage shredding in combination with sorting and segregation by physical criteria, such as density, particle shape and size, magnetic properties, conductivity, and visual appearance. The process is shown in Figure 4-3.

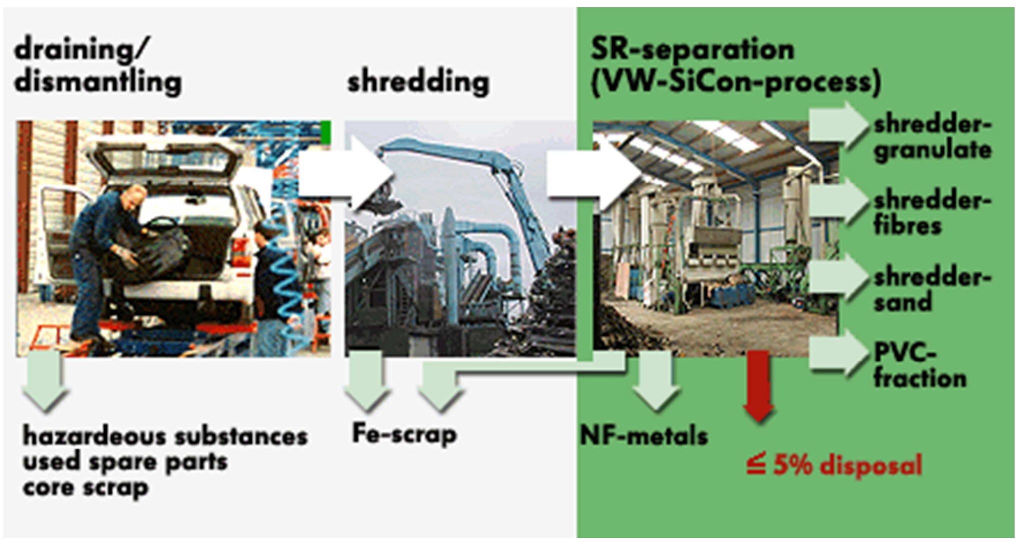


Figure 4-3: Overview of Volkswagen SiCon process (Source: VW-SiCon)

In order to separate poly-olefins from the shredder-granulate fraction SiCon technologies developed the Polyfloat process. Pilot plants were installed for demonstration of this process for separation of poly-olefins. The process assures the highest possible separation efficiency even with very small differences in the specific weight of plastics. This process is based on the density separation of plastics from shredder residue as well as electric and electronic scrap to achieve at least 99% purity of material. Polyfloat® is a fully automated process to adapt the density fluctuations and various density media are available for perfect separation of different plastics. Complete Polyfloat technology process sequence is shown in Figure 4-4.

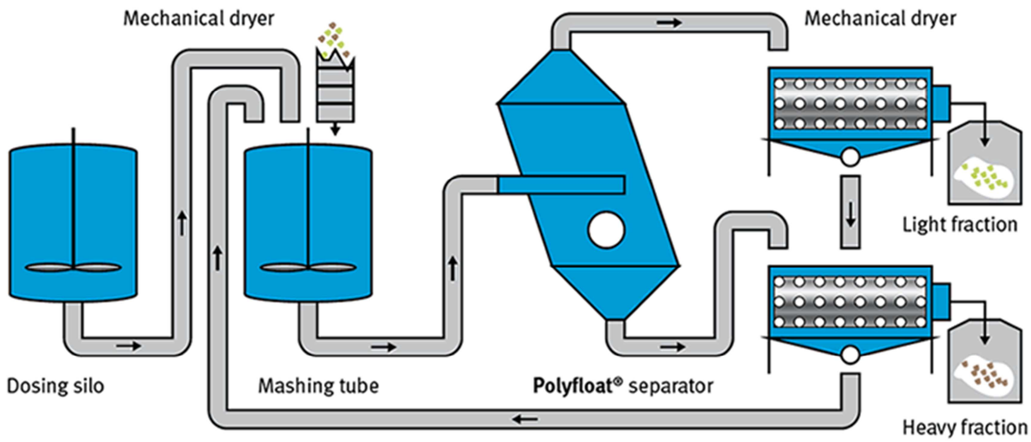


Figure 4-4: Polyfloat technology process overview (Source: VW-SiCon)

The main advantages of Polyfloat technology are:

- High-precision density separation.
- Automatic adaptation of the density fluctuation.
- Applicable for PE/PP, ABS/PS and other plastics.
- Environment-friendly design with integrated recovery and treatment of density media.

SiCon also developed FinesTuning process to recover valuable ferrous and non-ferrous metals from the ASR. FinesTuning makes use of powerful magnetic elements to separate components from the shredder residue. Approximately 20-30 % of shredder residue is fines, small sized materials that pass through the initial screening process. Depends on product mix approximately 5% are recyclable metals, these valuable metals are often landfilled. The innovative FinesTuning system recovers these valuable materials and allows shredder operators to receive benefit out of the fines.

The main advantages of this process are:

- Profit increase through fines recovery.
- Quick amortization of investment.
- Less transport and dumping costs.
- Space-saving and compact design allows easy.

With the cooperation of Siegen University (Germany), SiCon has developed a comprehensive concept to generate a hydrogen rich synthetic gas from biomass and /or substitute fuels. Starting from quality supply to assured substitution fuels, the ReEnvision concept comprises the whole chain of energy generation. Besides other applications, the synthetic gas generated by the ReEnvision process may be used as fuel gas. ReEnvision is a major component for entering the hydrogen supply and distribution sector. The complete ReEnvision process is depicted in Figure 4-5.

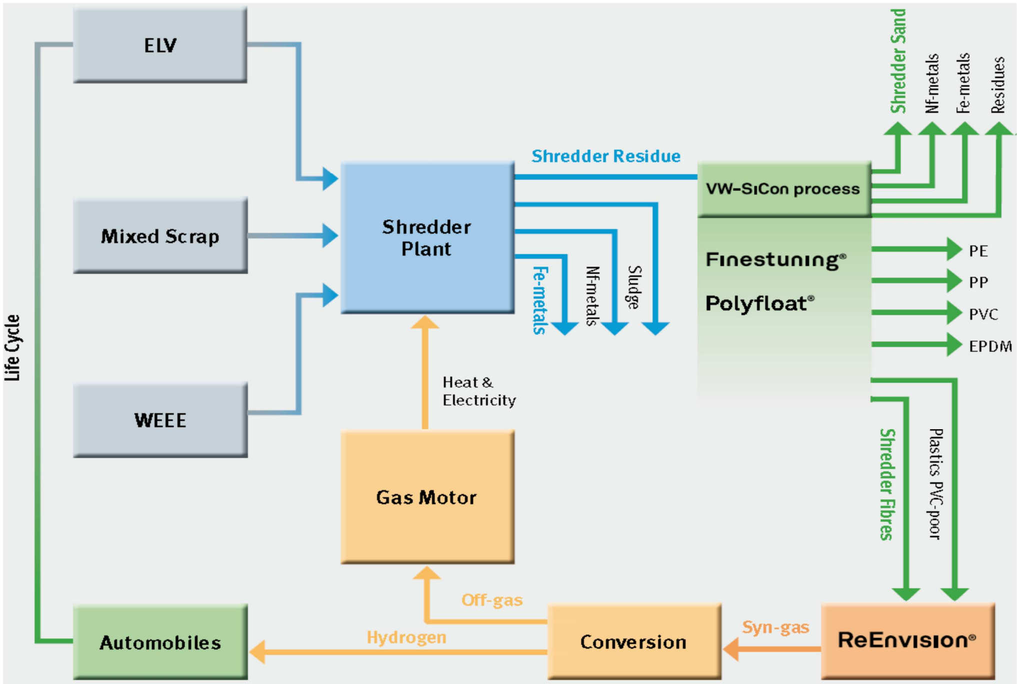


Figure 4-5: The process of ReEnvision (Source: VW-SiCon)

4.4.2 The Galloo recycling process

Galloo group is one of the European leading recycling companies established in 1939. Galloo group is divided into Gallo Metals and Galloo Plastics. There are 17 divisions in Belgium, 19 in France and one in the Netherlands. The Galloo recycling process is a multi-step process for treating end-of life vehicles. The process steps are depollution, dismantling, shredding and treatment of the ASR for further processing. [25]

The basic steps in Galloo's process are:

- Shredder residue is an average particle size of about 25 mm.
- A series of mechanical separation processes (including trommels and air classifiers) are used to produce a plastics concentrate.
- A series of density separation stages are used for further separation. These include stages at specific gravities of 1.6, 1.25, 2.2, and 3.2.
- Proprietary gravity separation processes are used to separate plastics having specific gravity values between 0.9 and 1.5.

In the Galloo process a series of four different dense media separation drums is used for the treatment of ASR. The first media (1.6 g/cc) separates organics from inorganic materials, second density media (1.25 g/cc) separates PVC, third density media (2.2 g/cc) and fourth density media (3.2 g/cc) is used to reclaim valuable materials from a fraction containing plastics like ABS and nylon.

After the bulk separation of shredder residue with non-ferrous metals fraction of 5.4% and other fractions recovered including mineral fraction (40%) which is currently disposed of in landfills, but evaluating to use for road construction, light fraction (30%) consists of primarily foam and textiles, Galloo investigating the feasibility of using this fraction for exterior sound insulation, Heavy combustible fraction (15%) consists of mainly rubber, wood, and other polymers. Because of the rubber content this fraction has a relatively high calorific value and it used as a cement kiln fuel. Plastics fraction (10%) and Remaining residues (5%) contains PVC, non-ferrous metals, and stone and rock. this fraction is processed in a heavy-media separation plant to recover the non-ferrous metals, stone and rock are used in road construction, and remaining is disposed. [(28)]

In ASR treatment process, with a shredder residue treatment line (SRTL) route, light thermoplastics fraction separated from heavy thermoset fraction by using a rotating cylindrical screen, with a subsequent air classification stage removing textiles and polyurethane foam. Using eddy-current separators, copper is recycled from the remaining thermoplastics and thermoset rubber portion. The thermosets are used by Galloo as a fuel. This plastics stream is composed of 45% polypropylene, 21 % polyethylene, 6% polymethyl methacrylate (PMMA) and 4% acrylonitrile butadiene styrene (ABS). These are mixed with a percentage of other post-consumer plastics scraps and various chemical additives, before a subsequent extrusion process. In these extrusion lines multi-colored ground plastics converted into black pellets which can be used by plastics manufacturers. [(29)]

The process structure of Galloo is explained in Figure 4-6.

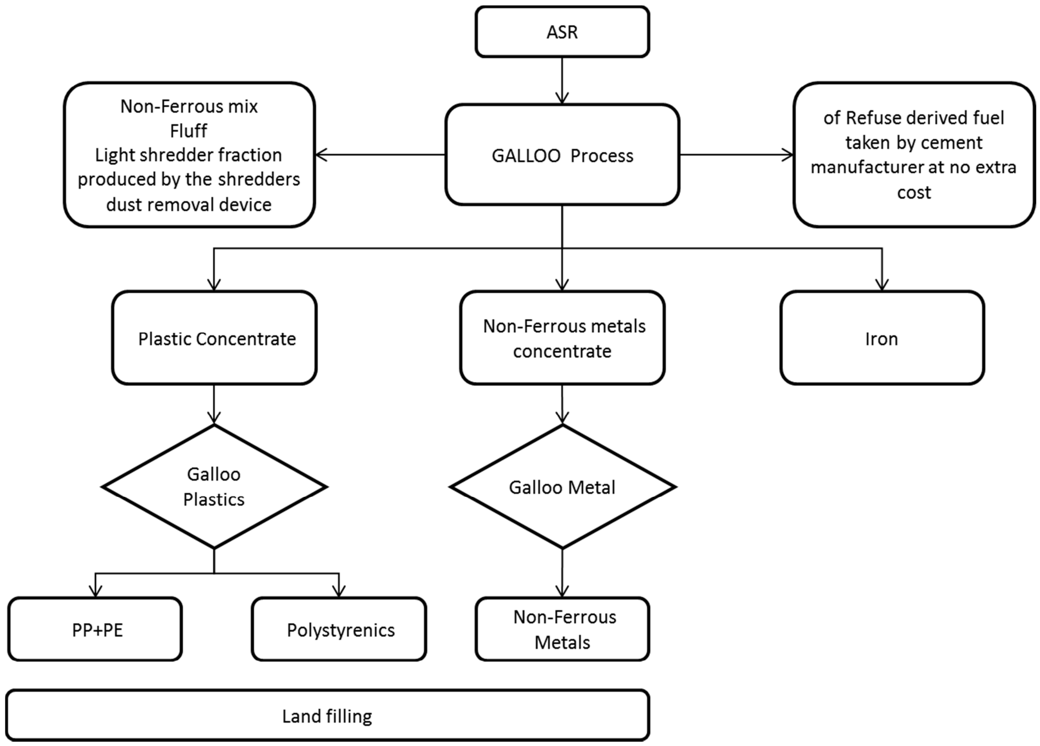


Figure 4-6: Galloo Process for recycling (Source: Annex III, EC)

4.4.3 Energy recovery and landfilling of ASR

Due to high calorific values of most ASR materials, a high percentage of the material mass is energy recoverable, although unprocessed ASR has high ash, heavy metal, and chlorine content.

Approximately 20 to 50 % of dry ASR is energy recoverable, especially plastics, fabric, and rubber. Incombustible materials include metals, glass, dirt, and ash. The first step in processing ASR for fuel use is the removal of incombustibles. The ASR is used as substitute to conventional fuels in cement kilns or blast furnaces. The use of ASR in cement kilns is better than in boilers because the kilns can tolerate high ash contents. A recent evaluation of ASR use in cement kilns conducted by the California Department of Toxic Substances Control suggests that, despite the obstacles of separating combustibles from incombustibles and reducing contaminant concentrations, processing ASR for use in cement kilns would be cost-effective compared to landfilling, due to the avoided transportation costs and tipping fees. [30]

Directive 1999/31/EC on the landfill of waste entered into force on 16th July 1999. The objective of this Directive is to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste by introducing stringent technical requirements for waste and landfills. According to this Directive landfills are divided into hazardous waste, non-hazardous waste and inert waste. The waste must be treated before being landfilled. Hazardous waste within the meaning of the Directive must be assigned to hazardous waste landfill. Non-hazardous waste and inert waste must be landfilled in appropriate landfills. Liquid waste, flammable waste, explosive or oxidizing waste, used tires and infections waste must not be landfilled. As a result landfilling of untreated waste materials of plastics is not allowed. Therefore ASR has to be recycled or energy recovered. In the European Union the number of permitted or legal landfills is decreased since the implementation of the Landfill Directive. The reasons are increased difficulties and costs associated with the siting, design, construction and operation of landfills. It is difficult and costly for site operators to comply with the Landfill Directive. After the introduction of the process steps of automotive recycling in Europe, the algorithm for the calculation of vehicle recyclability will be described in the following chapter. (31)

4.5 Calculation of vehicle recyclability (32)

Directive 2005/64/EC requires the calculation of vehicle recyclability and recoverability rates by using the algorithm described in standard ISO 22628:2002. The calculation method of this standard provides manufacturers with a methodology for calculating the recyclability and recoverability rates of vehicles for type-approval. The specifies a method for calculating the recyclability rate and the recoverability rate of a new road vehicle, each expressed as a percentage by mass of the road vehicle, which can potentially be recycled, reused or both (recyclability rate), or recovered, reused or both (recoverability rate).

The calculation method to calculate the recyclability and recoverability rates is carried out through the following four steps on a new vehicle:

- Pretreatment.
- Dismantling.
- Metals separation.
- Non-metallic residue treatment.

The materials breakdown of the vehicle is established by classifying all the materials composing the vehicle into the following seven categories:

- Metals.
- Polymers (excluding elastomers).
- Elastomers.

- Glass.
- Fluids.
- Modified organic natural materials (MONM) such as leather, wood, cardboard and cotton flee.
- Others (components/materials for which a detailed material breakdown cannot be established such as compounds, electronics, electrics).

The vehicle mass m_V is defined as complete vehicle shipping mass, as specified in ISO 1176, plus the mass of lubricants, coolant , washer fluid, fuel (tank filled to at least 90%), and if applicable also spare wheels, fire extinguisher, standard spare parts, chocks and standard toolkit.

4.5.1 Determination of partial masses m_P, m_D, m_M, m_{Tr} and m_{Te}

The calculation of the recyclability and recoverability rates in accordance with the standard ISO 22628 consists of the following steps shown in Figure 4-7.

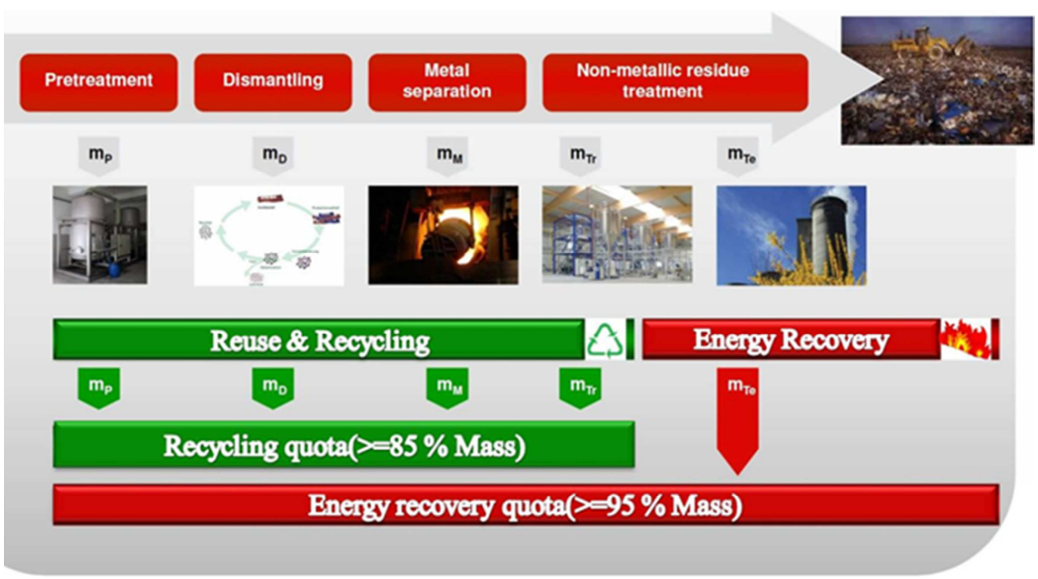


Figure 4-7: Recyclability and recoverability rates in accordance with the standard ISO 22628:2002 (Source: MAGNA STEYR)

Al the pretreatment step, the following vehicle components are considered as reusable/recyclable:

- All fluids.
- Batteries.
- Oil filters.
- Liquefied petroleum gas (LPG) tanks.

- Compressed natural gas (CNG) tanks.
- Tires.
- Catalytic converters.

The mass m_P is determined as the sum of the masses of these components and materials.

At the dismantling step, vehicle components are considered as reusable/recyclable based on the dismantlability (accessibility, fastening technology, proven dismantling technology), on the material composition and available proven recycling technologies. The reusability of components shall be subject to consideration of safety and environmental hazards. The mass m_D is determined as the sum of the masses of all the parts considered accordingly as reusable or recyclable.

At metals separation step, all metals, ferrous and non-ferrous, which have not already been accounted for in the previous steps are considered as recyclable. The mass m_M is determined as the sum of the masses of metal remaining in the vehicle after the previous steps.

The remaining other materials constitute the non-metallic residue. Residual non-metallic materials are considered as recyclable on the basis of proven recycling technologies (Determination of partial mass m_{Tr}). Residual non-metallic materials that can potentially be used for energy recovery are considered as recoverable (Determination of partial mass m_{Te})

4.5.2 Calculation of recyclability and recoverability rates

The recyclability rate, R_{cyc}, of the vehicle is calculated as a percentage by mass by using the following formula:

$$R_{cyc} = \frac{m_p + m_D + m_M + m_{Tr}}{m_V} \times 100$$

The recoverability rate, R_{cov}, of the vehicle is calculated as a percentage by mass by using the following formula:

$$R_{cov} = \frac{m_p + m_D + m_M + m_{Tr} + m_{Te}}{m_V} \times 100$$

The ability to facilitate the calculations of vehicle recyclability by using a capable software tool was the main motivation for MAGNA STEYR to develop the software tool ProdTect Automotive.

4.6 MAGNA STEYR approach

Vehicle manufacturers around the globe know MAGNA STEYR as a leading partner in the development and production of high quality vehicles. More than 100 years of automotive experience and many award winning high quality products have brought MAGNA STEYR into the position to be the first choice for OEMs worldwide as a global partner. With the implementation of the European directives 2005/53/EC car manufacturer have to fulfill several environmental requirements for the design and type-approval of vehicles. In addition to these legal requirements virtual automotive development has increased due to shortened development phases and reduction of prototype vehicles. MAGNA STEYR engineering targets are validated virtually by several simulation and calculation loops before physical validation.

4.6.1 Data management and software tool

An intense use of the internal and external automotive information systems PDM (Product Data Management) and IMDS (International Material Data System) is a precondition in order to ensure the availability of material and mass data for simulations. The management of data for the complex product automobile is a big challenge. For the calculation of vehicle recyclability, the IMDS in house data base IHS and the calculation software i.e. ProdTect Automotive is used by MAGNA STEYR. The data management at MAGNA STEYR is shown in Figure 4-8.

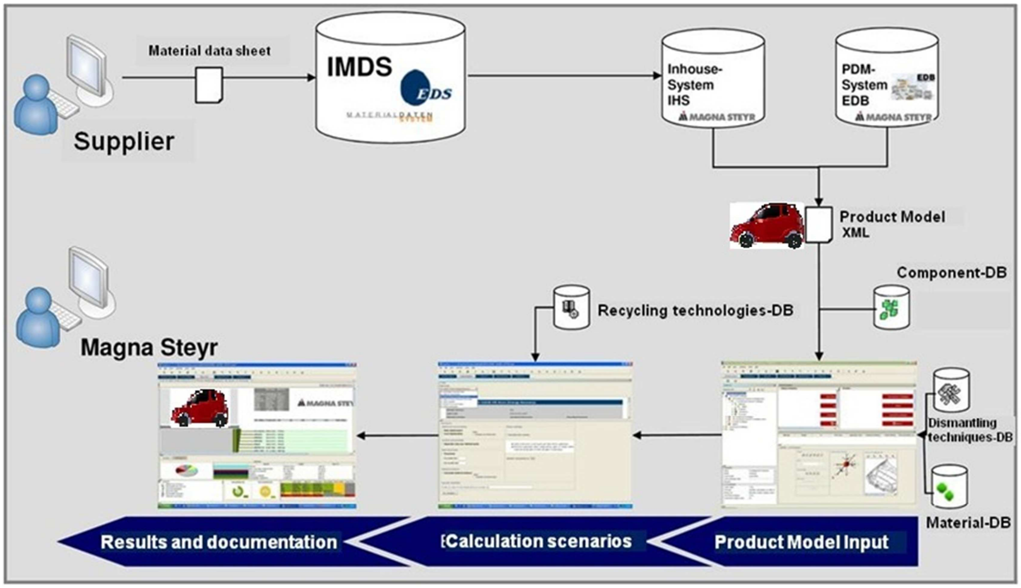


Figure 4-8: MAGNA STEYR approach calculation of vehicle recyclability (Source: MAGNA STEYR)

ProdTect Automotive is a simulation tool developed by MAGNA STEYR, KERP Engineering and the universities BOKU Wien and TU Braunschweig. This software tool is used to calculate the recyclability rate for E-MILA Student. ProdTect Automotive is a tool for calculating the type-approval and ISO 22628:2002 requirements and also a decision tool for designers regarding environmental improvements. ProdTect Automotive helps product developers to optimize material selection and product structure in order to match the constraints of design for recyclability in the most efficient way. The software consists of several data bases required for simulation and calculation of vehicle recyclability. The tool is based on a logical and clear assessment workflow that builds the foundation of transparency and controlling of the end-of life performance of a product from the early stages of its life cycle design by determining the weak points and the improvement possibilities of a product. [33] The workflow of ProdTect Automotive is shown in Figure 4-9.

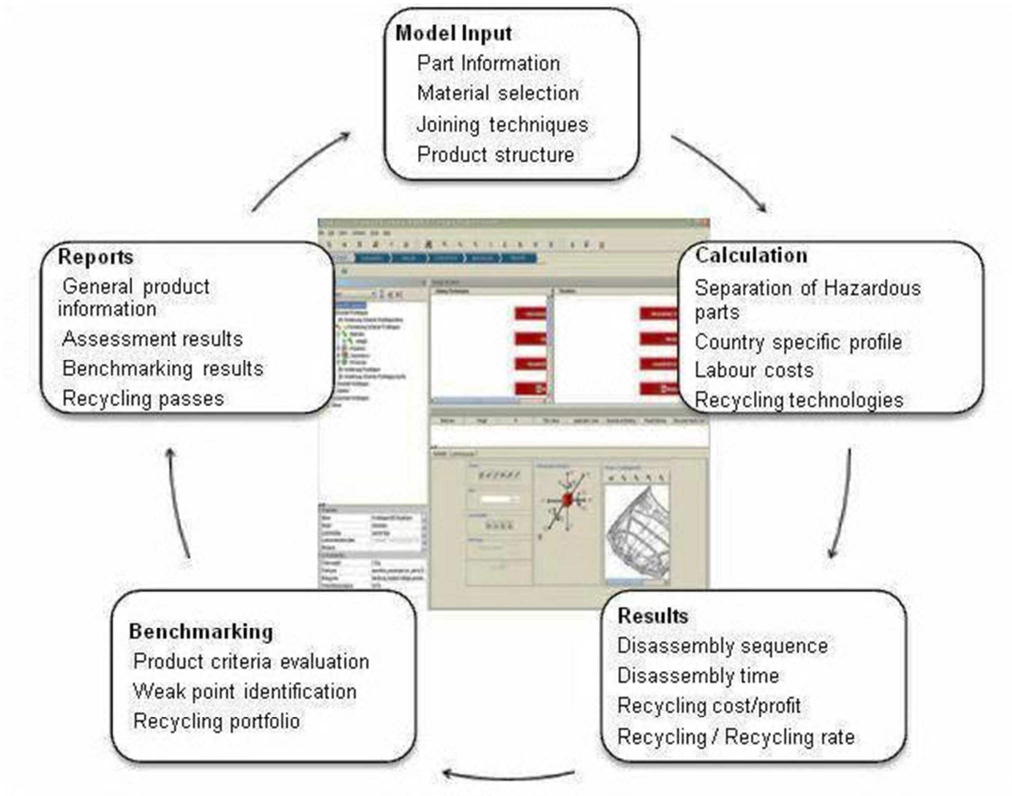


Figure 4-9: ProdTect Automotive workflow (Source: MAGNA STEYR)

4.6.2 Simulation of vehicle recyclability – the assessment process [34]

The vehicle model is the basis for the assessment process of the simulation tool (see Figure 4-10). It consists of information of components material, material masses, contained declarable substances and geometrical information regarding accessibility of target parts for pretreatment and dismantling.

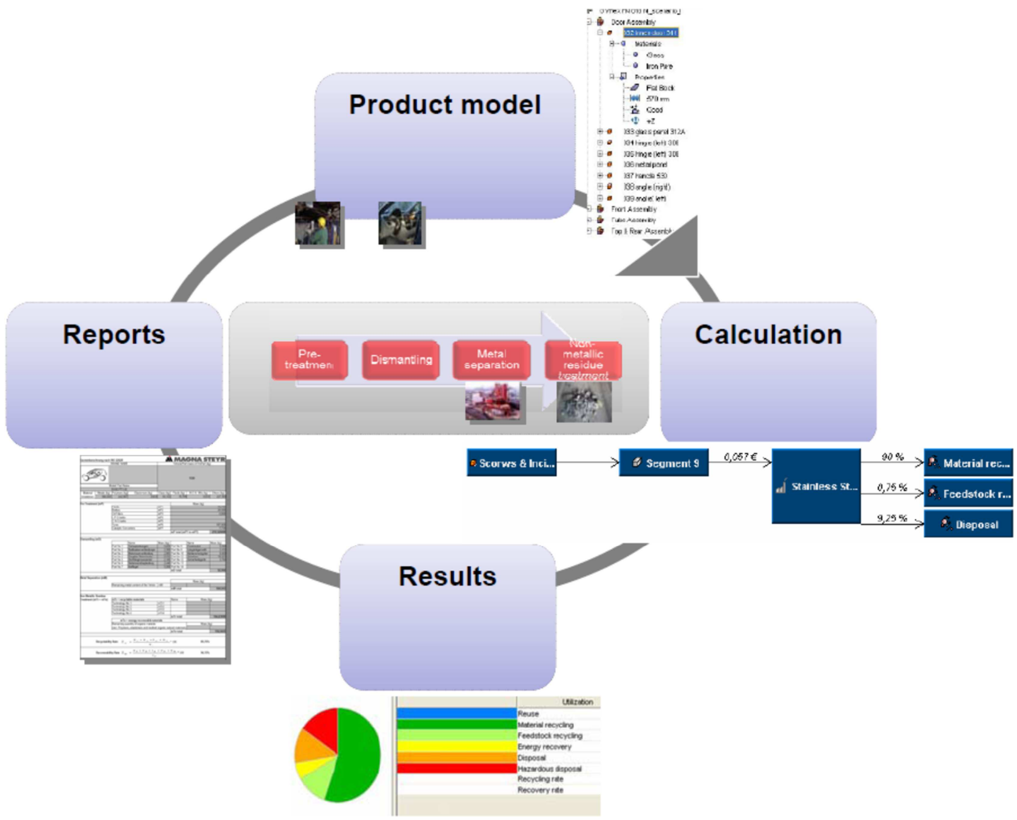


Figure 4-10: Assessment process of simulation tool (Source: MAGNA STEYR)

The product structure is represented by connecting elements and information regarding components priorities for vehicle disassembly. The software is able to identify target parts for pretreatment or dismantling according to ISO standard 22628:2002. For these target parts different scenarios regarding material, design or connecting technique can be calculated and effects on the vehicle recyclability and dismantlability can be simulated.

All vehicle materials refer to a material library in the software, where general material data are available for the calculation of the vehicle recyclability and recoverability rates. These materials are linked to proven recycling technologies in the recycling process library of the software tool. The calculation algorithm follows the calculation method of ISO standard 22628:2002 and the simulation of the vehicle recyclability is done by using the vehicle model of the recycling reference vehicle and the recycling profile according to ISO 22628:2002.

In Figure 4-11, the assessment process of ProdTect Automotive is shown. The assessment process starts with the model input where the material information, joining techniques, product structure and component geometry information such as dimensions, shape and accessibility of components are defined. By using this information in the calculation step, the environmental performance of the products can be assessed depending on the selected recycling profile and scenario. In the result step, the required information regarding materials breakdown, recycling quota and dismantling information is available. In the report step, it is possible to get the reports required for type-approval (e.g. ISO 22628:2002 data presentation) and also reports for internal purpose (e.g. detailed materials breakdown, end of life values and an overview of dismantled parts of the vehicle). (33)

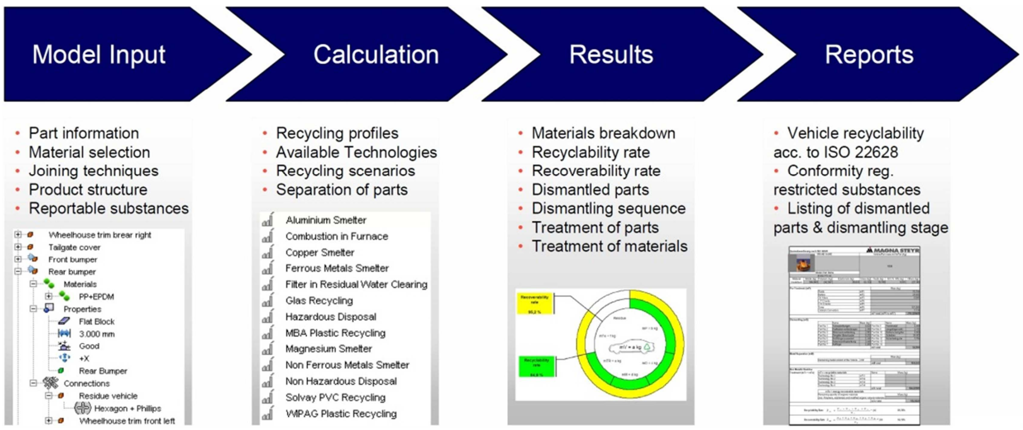


Figure 4-11: ProdTect Automotive software assessment process (Source: MAGNA STEYR)

ProdTect calculations are performed based on a product model, which holds all the necessary details of the evaluated product. In the first step a complete list of components of the vehicle is generated in the PDM system. In the second step material and mass data are added from the internal MAGNA STEYR IMDS system (IHS). For E-MILA Student project no product data management (PDM) is available for generating the product model. The Student EMILA car model input was created manually in ProdTect. In Figure 4-12, the default screen of the model input to the workflow bar is shown.

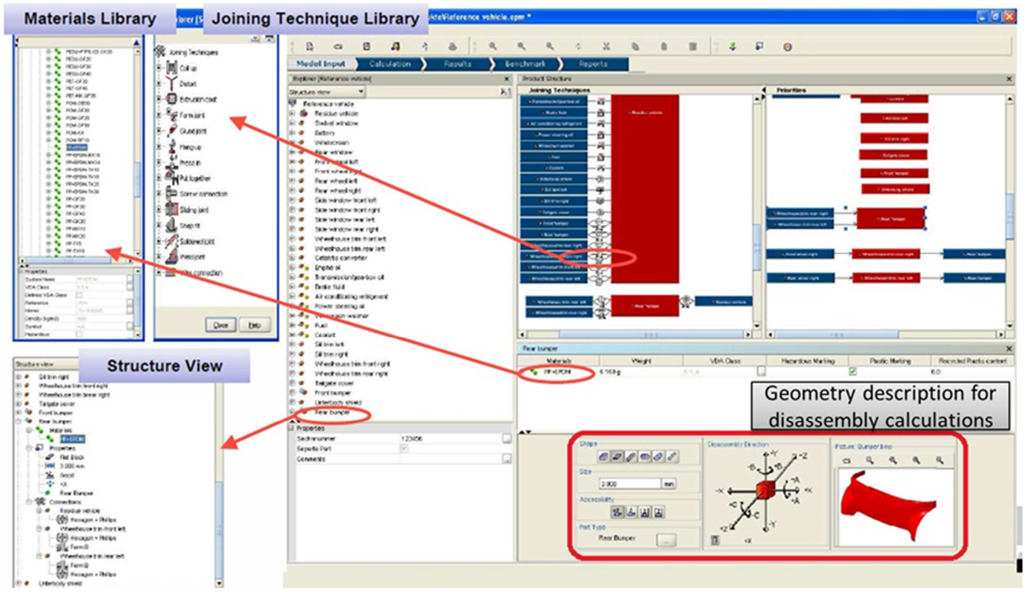


Figure 4-12 : Model input screen of the ProdTect Automotive (Source: MAGNA STEYR)

The model tree supports to navigate all the assemblies and parts easily. More details of parts like connections, material, datasets and properties can be found by expanding the part in the model tree. The joining techniques window shows the relationship between the parts. All possible joining techniques are available in the library. Geometry description and joining techniques are very important to calculate the dismantling time and cost. Material data for components can be selected from the material library of ProdTect Automotive. The material library contains all the materials used for automotive industry. The material class is structured according to the standard VDA 231-106. Once the model input is completed, the appropriate recycling scenarios must be selected to start the recycling calculations. In a first step, the disassembly of target parts for pretreatment (all fluids, batteries, oil filters, liquefied petroleum gas tanks, compressed natural gas tanks, tires and catalytic converters) is simulated. In a second step additional target parts for dismantling are determined in the vehicle model. These target parts are separated before the shredding of the vehicle and they are treated by defined recycling processes. The calculation algorithm determines the optimal depth of disassembly. The remaining materials which are not included in the pretreatment or dismantling step are treated by the shredder process and proven post-shredder recycling processes. The final step is to calculate the recycling quotas and obtain the reports for type approval of the vehicle.

5 E-MILA Student Project

The E-MILA Student project is to design an electric vehicle for the daily commuters with a maximum range of 90 km for daily travel. The car is designed initially for the European market and it is planned to introduce the vehicle later in Northern America and growing markets like India and China. Homologation and packaging of this car are designed according to European standards, so little efforts are required to introduce the E-MILA Student in other market segments. To solve the parking space problems the E-MILA Student vehicle is designed as small as possible without affecting the comfort and luggage space. Concept layout of E-MILA Student car is shown in Figure 5-1.

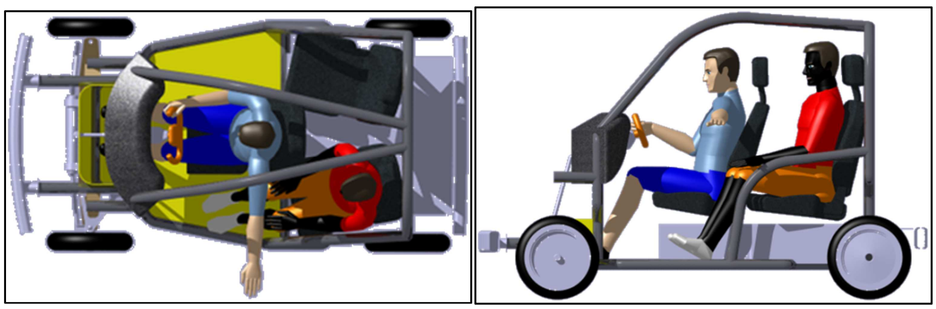


Figure 5-1: Layout of the E-MILA Student car (Source: MAGNA STEYR)

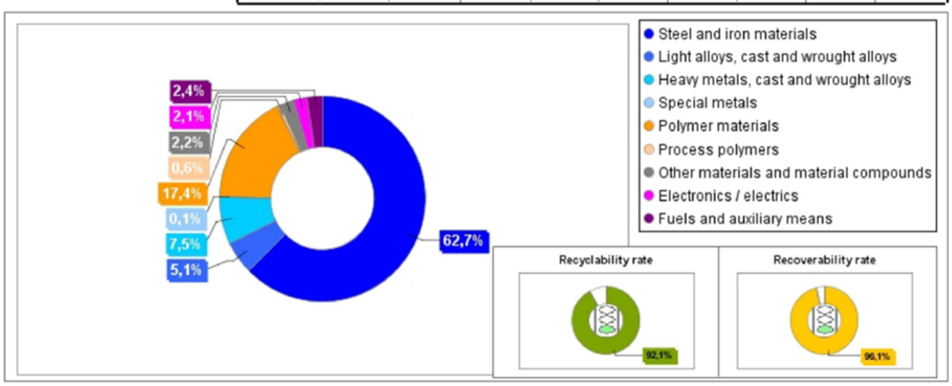
The E-MILA Student vehicle is designed for the category L7e. The main constraints of L7e segment compared to passenger cars are:

1. Maximum curb weight of vehicle is 400 kg (excluding lithium ion battery).
2. Maximum nominal engine power is 15 KW.

The main battery of the vehicle is based on lithium ion chemical composition with the capacity of 15 KW. It has range of 95 km and it takes 6 hours to fully recharge the battery. E-MILA Student battery supports a quick recharge. 80% of battery charging can be done in 45 minutes. The lithium ion battery is placed under the rear seats because of packaging convenience. This electric car provides remarkable storage space of approximately 180 liters behind the rear seats. The complete features of the E-MILA Student car are shown in Appendix-1.

The most exciting feature of E-MILA Student car is the material composition of 97% of recoverable materials which indicates clear green image of this car. Considering the maximum recyclability of all the scenarios show in Table 6-2 , approximately 97% of materials can be recovered by Galloo recycling process. The breakdown of materials of the E-MILA Student car according to standard VDI 231-106 is shown in Figure 5-2. The material PP-GF40 is used for all interior components of the E-MILA Student to reduce the variety of materials. This material can be separated and recycled by Galloo post-shredder technology. The complete bill of material (BOM) of E-MILA Student car is shown in Appendix-2.

Brand name:	Student E-M	Model :			Total Mass, mV:		549,7	Kg
Materials Breakdown	Steel and iron materials	Light alloys, cast and wrought alloys	Heavy metals, cast and wrought alloys	Special metals	Polymer materials	Process polymers	Other materials and material compounds	Electronics / electrics	Fuels and auxiliary means
	Mass (Kg)								
	344,7	28,1	41,1	0,3	95,7	3,1	11,9	11,3	13,4



Profile	Profile: ISO 22628 PST Scholz & Galloo | Scenario: Rate Optimization			
User				
Date	08.10.2010	Time	13:49:29	Page 1 of 1

Figure 5-2: Material balance sheet according to VDI 231-106 (Source: MAGNA STEYR)

5.1 Pretreatment and dismantling of E-MILA Student

The first step of the recycling process is pretreatment. In this process, following fluids and parts can be recovered from the E-MILA Student vehicle after end-of life.

- Brake fluid.
- Windscreen washer fluid.
- Power steering oil (Optional equipment).
- Shock absorber fluid.
- Transmission/gearbox oil.
- Batteries.
- Hydraulic suspension fluid.
- Tires.
- Coolant.

In the process of dismantling, the following parts shown in Figure 5-3 are target parts for dismantling for the E-MILA Student vehicle. Due to the expensive dismantling process the some of the target parts are dismantled based on the post-shredder technologies to fulfill the legal requirements.

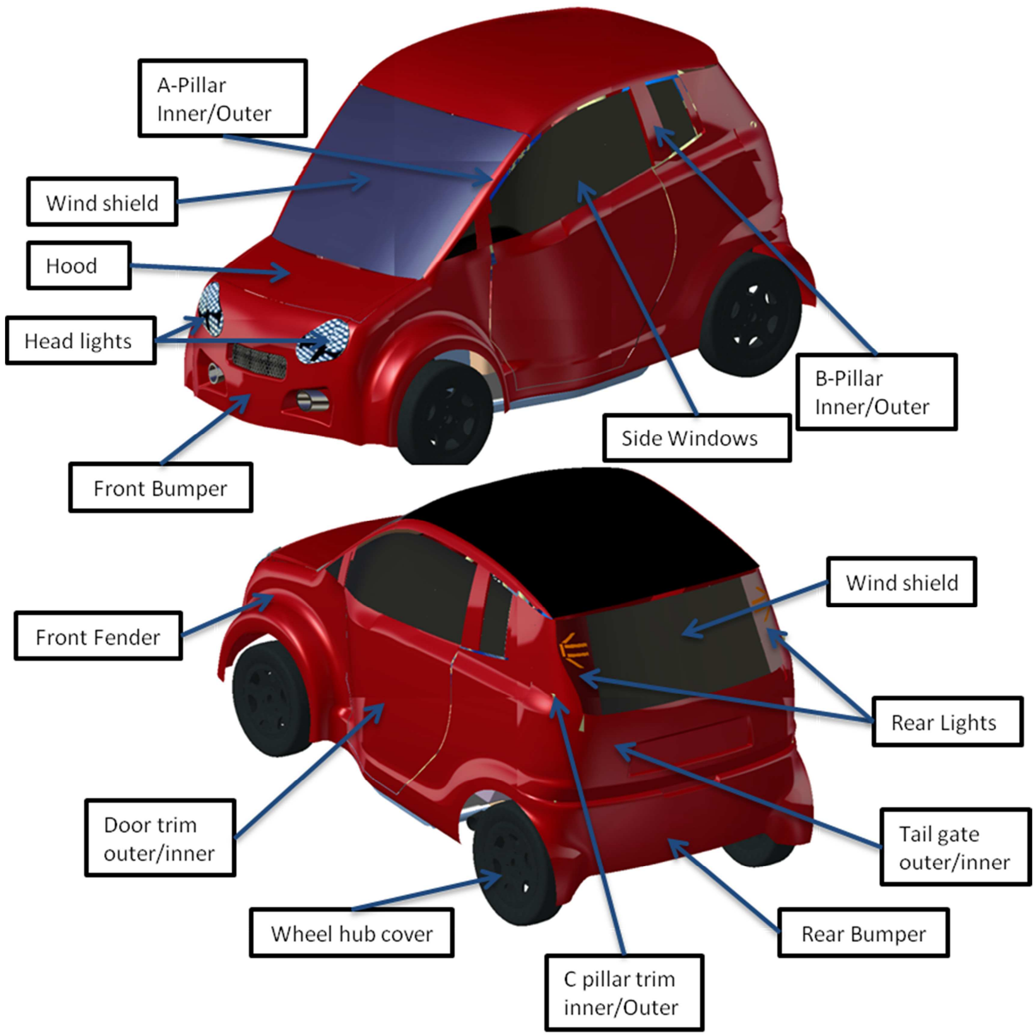


Figure 5-3: Parts of interest for dismantling of E-MILA Student vehicle

5.2 Recycling quota calculations

Currently there are no regulations regarding recyclability for L7e class segment vehicles, but the vehicle type-approval system with regard to the vehicle recyclability will be extended to all categories in the near future. For this study, ELV regulations for M1 class segment vehicles are considered for the calculation of the recycling quota. ProdTect Automotive is a very comprehensive recycling calculation tool. It is possible to calculate different recycling scenarios depending on local conditions and requirements. ProdTect Automotive is used to calculate the Student EMILA car recyclability according to three recycling scenarios described in chapter 6.

Data presentation
ISO 22628:2002

MAGNA STEYR

Brand name:	Magna Steyr	Vehicle mass, mV:	399,7 kg
Model (type/ variant):	Student EMILA		

Materials Breakdown	Metals	Polymers (exl. elastomers)	Elastomers	Glass	Fluids	MONM	Others
Mass (Kg)	298,8	56	17,6	8,8	6,4	0	12,1

Pretreatment (mp)		Mass (kg)
Fluids	mp1	5,9
Battery	mp2	7,5
Oil filters	mp3	0
LPG tanks	mp4	0
CNG tanks	mp5	0
Tyres	mp6	41,2
Catalytic converters	mp7	0
	mp total (sum mp1 to mp7) =	54,6

Dismantling (mD)

Part Number	Name	Mass (Kg)	Part Number	Name	Mass (Kg)	Mass (part 11 to 36) (kg)	
1	RR WINDOW	4,7	6	Assy trim	1,2	mD36	15
2	Wind Shield	4,5	7	Assy trim	1,2		
3	Front bumper	2,5	8	Front Door	1,2		
4	Rear bumper	2,3	9	Front Door	1,2		
5	Tailgate outer	1,2	10	SEATBELT	1		
mD1 total (sum 1 to 5)		15,2	mD2 total (sum 6 to 10)		5,8	mD total (mD1 + mD2 + mD36) =	36

Metal separation (mM)		Mass (Kg)
Remaining vehicle metallic content:	mM=	269

Non-metallic residue treatement (mTr and mTe)

Recyclable materials (mTr)			Mass (Kg)
Technology no.	Name		
1	Galloo Plastics	mTr1	15,3
2		mTr2	
3		mTr3	
		mTr total (sum mTr1 to mTr1	15,3
Energy recoverable materials (mTe)			Mass (Kg)
Remaining quantity of organic materials (polymers, elastomers etc.):		mTe =	14,2

Recyclability rate	Rcyc = [(mP + mD + mM + mTr) / mV] x100	94 %
Recoverability rate	Rcov = [(mP + mD + mM + mTr + mTe) / mV] x100	97 %

Figure 5-4: Recycling quota of E-MILA Student vehicle without lithium ion battery according to ISO 22626:2002 (PST Galloo)

In Figure 5-4, the recyclability rate and recoverability rate of E-MILA Student vehicle excluding the lithium ion battery are shown according to ISO 22628:2002 (PST Galloo). With reference to standard ISO 22628:2002 all the pretreated and dismantled parts are considered to be 100% recyclable. In the case of E-MILA Student, lithium ion battery which is one third of the weight of the complete vehicle is pretreated and is considered to be 100% recyclable. Because of that, recycling rates of E-MILA Student vehicle are significantly higher than conventional vehicles and they are not representation of the actual recycling situation of these batteries. In real situation there are no proven technologies to recycle 100% of lithium ion batteries at present.

Additionally rapid changes in chemical composition of these batteries make the recycling more difficult.

After the process steps of pretreatment, dismantling and metal separation and non-metallic residue treatment, the remaining material is undefined residue. The material breakdown of undefined residue in the scenario PST Galloo is shown in Table 5-1.

Material	Weight	Rate	VDI Material Class
Other fuels and auxiliary means	2.823	0.013%	9.8
Lubricants	411.946	1.894%	9.2
Other compounds	1319.073	6.066%	7.3
Ceramics /Glass	9189.547	42.261%	7.2
Electrics	49.427	0.227%	8.2
Electronics (e.g. PCB, Display)	383.44	1.763%	8.1
Electronics/electrics	8000	36.790%	8
Lacquers	2014.125	9.263%	6.1
Adhesives, sealants	22.615	0.104%	6.2
Polymeric compounds	351.295	1.616%	5.5
Thermoplastics	0.535	0.002%	5.1

Table 5-1: Material breakdown of undefined residue for scenario PST Galloo

It is clearly noticeable that the majority of materials of the undefined residue are ceramics/glass and electronics/electrics. Glass is only recyclable when it is dismantled. There are no proven technologies are available to separate glass economically from ASR. Approximately 40 % of the undefined residue is electronics and electric materials.

6 Comparison of defined recycling scenarios

For Identification of the cost-effective recycling solution for the E-MILA Student vehicle, two scenarios with very common post-shredder technologies (PST VW-SiCon and PST Galloo) and one scenario without using post-shredder technology were defined for comparison. The recycling processes in the pretreatment and metal separation step are equal in all scenarios and the main difference is the number of dismantled parts in the dismantling step and the treatment of the non-metallic ASR. In fact for E-MILA Student car, the target recyclability rate is achieved without any additional dismantling of parts after the pretreatment because of the weight portion of lithium ion battery which is always considered to be recyclable according to the standard ISO 22628:2002. Hence, achieving ELV recycling targets for E-MILA Student is effortless and there is no significant difference in the recycling processes in all the scenarios. Since the treatment of the lithium ion battery is also equal for all the scenarios, the calculations are performed for E-MILA Student vehicle excluding the lithium ion battery. For all three scenarios vehicle recycling costs are compared with minimum fulfillment of the legal recycling rates (85% recyclability rate, 95% recoverability rate).

6.1 Recycling calculations of the scenarios

In this chapter, a brief description is given on the scenarios regarding process and material flow information. The calculations of E-MILA Student vehicle are accomplished by excluding the lithium ion battery. Hence, total mass of the end-of life vehicle is approximately 400 kg.

6.1.1 Scenario 1: ISO Simplified – Energy recovery of non-metallic ASR

In this scenario the non-metallic ASR is not recycled but most of the non-metallic ASR is energy recovered. The material flow of this process is shown in Figure 6-1. Since there is no non-metallic ASR treatment for recycling, increased dismantling of parts is necessary to achieve the required recycling rates even though dismantling is expensive. These dismantled parts are treated by Wipag Süd GmbH & Co KG. Wipag is a partner of the automotive industry for the recycling of plastic components. The first step of the process is to separate impurities and foreign materials before the paint is removed. Melting of fine filtrations including re-compounding to the requested content, result in high quality PP/EPDM-TX recyclates. [35] In this scenario the dismantled components from E-MILA Student are Assy trim door outer LH&RH, C-pillar trim outer LH&RH, Front bumper, Rear bumper and Trim hood. The total mass of the dismantled parts (m_D) is 12.6 kg. In the metal separation process ferrous and non-ferrous metals are treated separately according to the type of material.

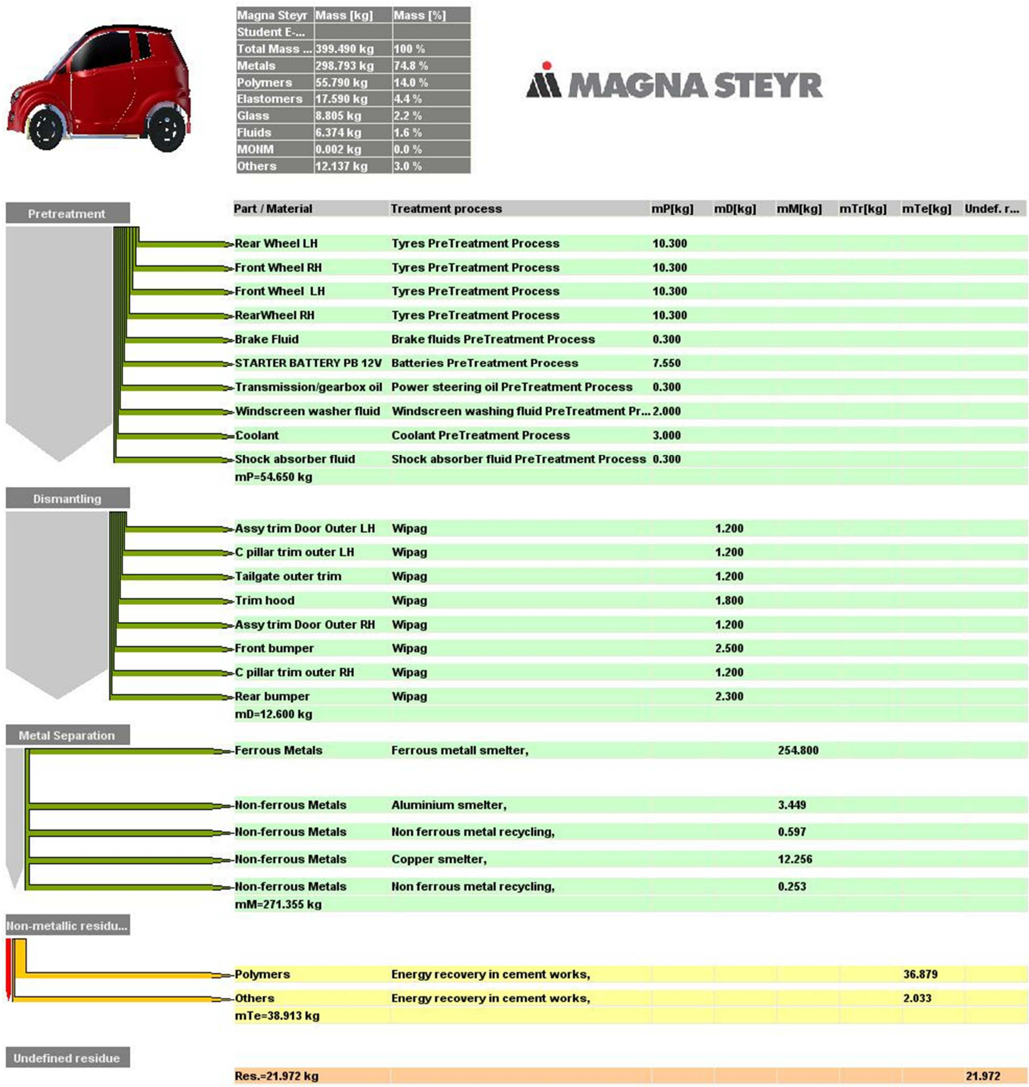


Figure 6-1: Material flow chart of recycling scenario ISO Simplified

The total material mass of the separated metals (m_M) is 271.35 kg. In the non-metallic residue treatment step 38.91 kg high calorific valued materials have to be energy recovered in order to fulfill the legally required recyclability and recoverability rates. Total undefined residue in this process is 21.97 kg.

6.1.2 Scenario 2: PST VW-SiCon – Post-shredder recycling of non-metallic ASR

In this scenario the non-metallic ASR is treated by the VW-SiCon post-shredder technology. The detailed material flow chart of the recycling process is shown in Figure 6-2. In this scenario the target recycling quota is achieved by additional dismantling of the bumpers and the trim hood of the

E-MILA Student vehicle. The total material mass of dismantled parts (m_D) is 6.6 kg. In the metal separation process ferrous and nonferrous metals are treated. The total material mass recovered during the metallic separation process (m_M) is 271.255 kg. The remaining ASR is treated by the VW-SiCon post-shredder technology. The four major output fractions of VW-SiCon separation technology are shredder granulate, shredder-fibers, shredder-sand and PVC fraction. The PVC fraction is recycled in the Vinyloop process developed by Solvay. The shredder fibers with a total mass of 4.93 kg are a mixture of textiles, seat foams and MONM. They are used in sewage sludge dewatering agent instead of coal dust. The mass of the shredder granulate in this process is 39.95 kg. This fraction contains plastics and elastomers that are energy recovered in the blast furnace. The rest material mass 21.97 kg is undefined residue.

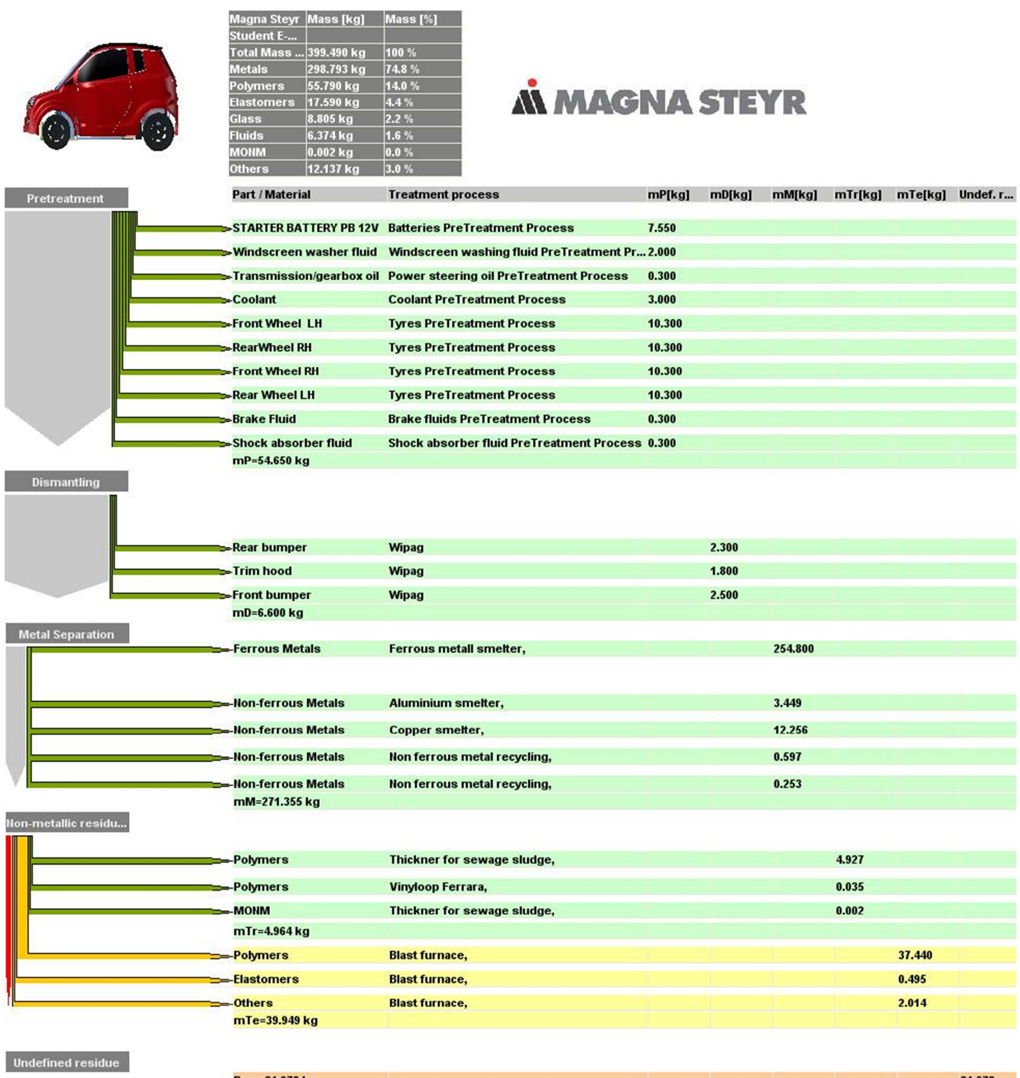


Figure 6-2: Material flow chart of PST VW-SiCon recycling scenario

6.1.3 Scenario 3: PST Galloo – Post-shredder recycling of non-metallic ASR

In this scenario the non-metallic ASR is treated by the Galloo post-shredder technology. The detailed material flow chart of the recycling process is shown in Figure 6-3. After pretreatment, the complete vehicle is shredded and ferrous and non-ferrous metals are separated from the shredder residue. The remaining shredder residue is treated by the Galloo process. The main advantage of this process is that the required target recycling quota can be achieved without additional dismantling of any components. E-MILA Student vehicle contains approximately 16 % of plastics in ASR which are recyclable with Galloo technology. In this recycling process plastics are separated by using different density media drums. The total plastics material mass separated during this process (m_{Tr}) is 11.56 kg. 8.0 kg of polymers, MONM and elastomers are energy recovered at cement works and 32.17 kg of polymers are energy recovered in blast furnace. Total energy recovered material mass (m_{Te}) is 40.18 kg. The undefined residue material mass is 21.75 kg.

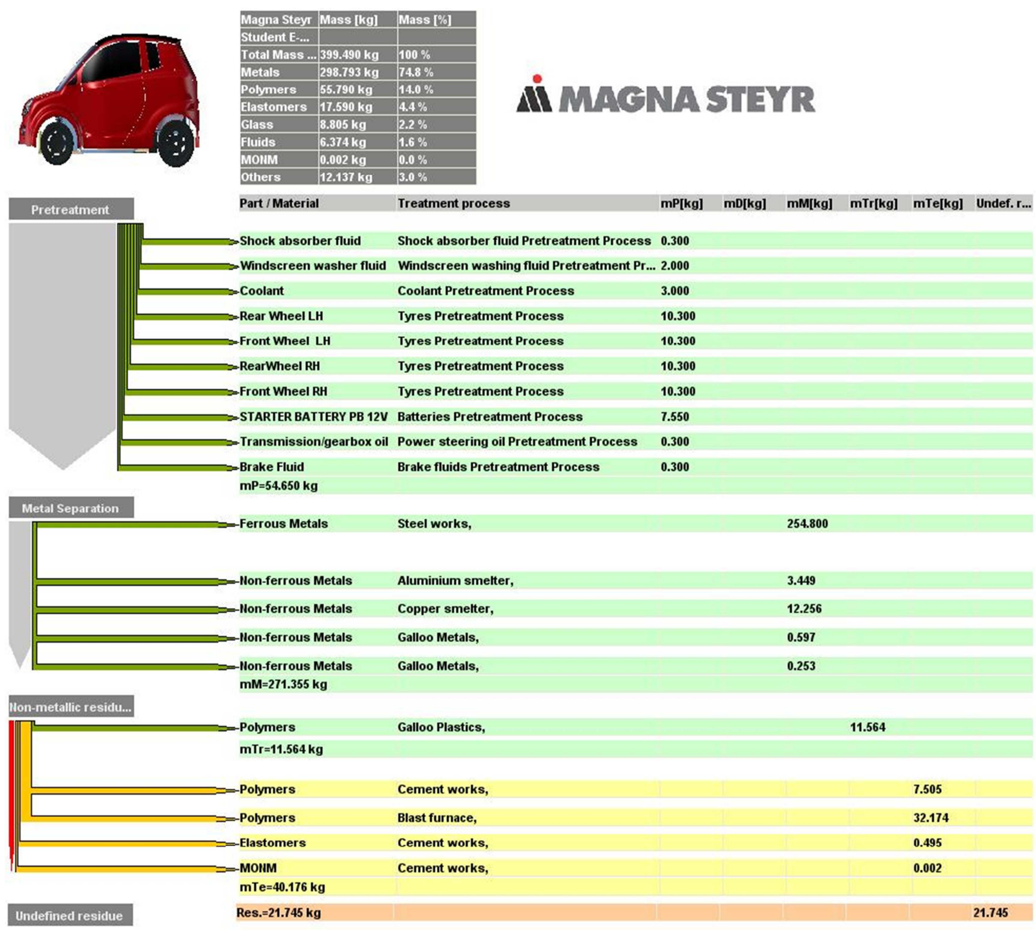


Figure 6-3: Material flow chart of PST Galloo

6.2 Comparison of results

Comparison of all the scenarios is discussed briefly in this chapter. E-MILA Student recycling processes, recyclability and recoverability rates and costs for legal compliance are taken into consideration for the comparison.

6.2.1 Recycling process comparison

In this comparison study, material flows of three scenarios are discussed briefly. The first step of ELV treatment is the pretreatment process, which is equal in all the scenarios. The second step is the dismantling of additional components. In this step there are significant differences regarding the number of dismantled parts required to fulfill the legal recycling targets. The material flow comparison of all three scenarios is shown in Table 6-1.

In order to fulfill the vehicle type approval regulation, additional dismantling of components is required for scenario 1(ISO Simplified) and scenario 2 (PST VW-SiCon). For scenario 3(PST Galloo), no additional dismantling of components is required after the pretreatment of the vehicle because of the separation and recycling of the polyolefins by using Galloo post-shredder technology.

The mass taken into account at the metal separation step is equal in all scenarios. The major difference can be found in the ASR treatment process. In scenario 1, after metal separation process 38.91 kg of high calorific material in the non-metallic ASR is incinerated in cement works. In scenario 2, the non-metallic ASR is further treated by new technologies and then largely recycled. PVC is separated and recovered by the Vinyloop process. The shredder fibers are used in sewage sludge dewatering and the shredder granulate is energy recovered in blast furnace. In scenario 3, polyolefins are separated from the shredder granulate and recycled by Galloo plastics. The remaining non-metallic ASR is energy recovered in blast furnace and cement works.

Comparison of three scenarios		Part/Material	Treatment process	Scenario 1 (ISO Simplified) (kg)	Scenario 2 (PST VW-SiCon) (kg)	Scenario 3 (PST Galloo) (kg)
Pretreatment		Shock absorber fluid	Shock absorber fluid Pretreatment Process	0.3	0.3	0.3
		Windscreen washer fluid	Windscreen washing fluid Pretreatment Process	2	2	2
		Coolant	Coolant Pretreatment Process	3	3	3
		Rear Wheel 1H	Tires Pretreatment Process	10.3	10.3	10.3
		Front Wheel 1H	Tires Pretreatment Process	10.3	10.3	10.3
		Rear Wheel RH	Tires Pretreatment Process	10.3	10.3	10.3
		Front Wheel RH	Tires Pretreatment Process	10.3	10.3	10.3
		Starter Battery PB 12V	Batteries Pretreatment Process	1.55	1.55	1.55
		Transmission/Gearbox oil	Power steering oil Pretreatment Process	0.3	0.3	0.3
		Brake Fluid	Brake fluids Pretreatment Process	0.3	0.3	0.3
Mass of Pretreatment		**m_P**		**48.65**	**48.65**	**48.65**
Dismantling		Front Bumper	Wipag	2.5	2.5	
		Rear Bumper	Wipag	2.3	2.3	
		Trim hood	Wipag	1.8	1.8	
		Assy trim Door outer LH	Wipag	1.2		
		Assy trim Door outer RH	Wipag	1.2		
		Tailgate outer trim	Wipag	1.2		
		C-Pillar outer trim RH	Wipag	1.2		
		C-Pillar outer trim LH	Wipag	1.2		
Mass of Dismantling		**m_D**		**12.6**	**6.6**	**0**
Metal Separation		Ferrous metals	Ferrous Metal Smelter	254.8	254.8	254.8
		Non-ferrous metals	Aluminum Smelter	3.449	3.449	3.449
		Non-ferrous metals	Copper Smelter	12.256	12.256	12.256
		Non-ferrous metals	Non-Ferrous metal recycling	0.85	0.85	0.85
Mass of Metals		**m_M**		**271.355**	**271.355**	**271.355**
Non-Metallic residue treatment (ASR)	**Recycling**	Polymers (Including PVC)	Galloo Plastics			11.564
		Polymers and MONM	Thickener for sewage sludge		4.929	
		PVC	Vinyloop		0.035	
		m_{Te}		**0**	**4.964**	**11.564**
	Energy Recovery	Polymers/Elastomer/ MONM	Cement works			8.002
		Polymers/Elastomer/ MONM	Blast furnace	38.913	39.949	32.174
		m_{Tr}		**38.913**	**39.949**	**40.176**
Undefined Residue				**21.972**	**21.972**	**21.745**
Recyclability rate / Recoverability rate				**85% / 95%**	**85% / 95%**	**85% / 95%**

Table 6-1: Material flow chart comparison for scenarios 1, 2 & 3

6.2.2 Recycling quota Comparison

Possible maximum recyclability rate and recoverability rates of all the scenarios are shown in Table 6-2.

Scenario	Recyclability rate	Recoverability rate
ISO Simplified	86.7	95.2
PST VW-SiCon	87.2	95.2
PST Galloo	93.8	97.4

Table 6-2: Comparison of recycling quota of scenarios (Source: MAGNA STEYR)

It is exciting to compare the results on the recyclability rate and recoverability rates of these scenarios. All the scenarios reach the European targets, but scenarios 3 achieved higher recycling rates than other scenarios because, Galloo has technology to recover polyolefins from non-metallic ASR. Research and development of respective companies are working to develop better processes to improve environmental performance as well recycling rates. Recycling quota of E-MILA Student by all the scenarios according to ISO 22628:2002 are show in Appendix-3.

6.2.3 Costs comparison of scenarios

In this comparison study, economic benefits of the scenarios are discussed briefly. The main difference in the material flows of all the scenarios starts from dismantling. In scenario 1 and 2 the additional dismantling of components for recycling is required to meet the legal recyclability rate. Total dismantling time for each scenario is required to find out the total dismantling costs. The total disassembly time is the addition of the handling time, the sum of the time required to take and position the tool, the time to disassemble a joining element, get to the next joining element and put the tool and part away. Dismantling is not only a time consuming process but also very expensive in Europe. Labor costs and costs for the transport of the vehicle to the dismantling factory. The market prices for recycled PP pellets range from 700 to 1000 €/ton depends on the quality. The processing costs range from 600 to 1000 €/ton. This means that the value of dismantled parts is around 0 €/ton to 200 €/ton. [36] In other words only very high quality parts which are easy to dismantle are really interesting for recycling.

The total time and breakdown timings for the dismantling of components in scenario 1 are shown in Figure 6-4. In this scenario the total dismantling time is 1588.49 seconds. Considering the labor costs of 25 €/hr, the total dismantling cost is 11.03€. The total mass taken into account at the dismantling step for this scenario is 12.6 kg.

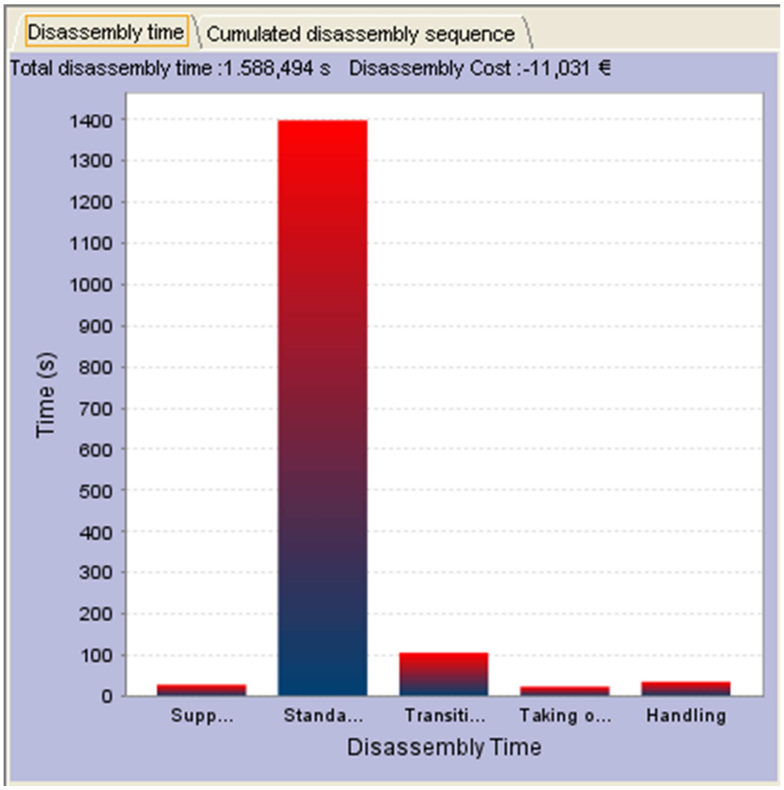


Figure 6-4: Dismantling time breakdown for scenario 1(Source: MAGNA STEYR)

The total time and breakdown timings for dismantling the parts for the scenario 2 are shown in Figure 6-5. In this scenario the total dismantling time is 1347.9 seconds. Considering the labor costs of 25 €/hr, the total cost required to dismantle the components is 9.36€. The total mass taken into account at the dismantling step for this scenario is 6.6 kg.

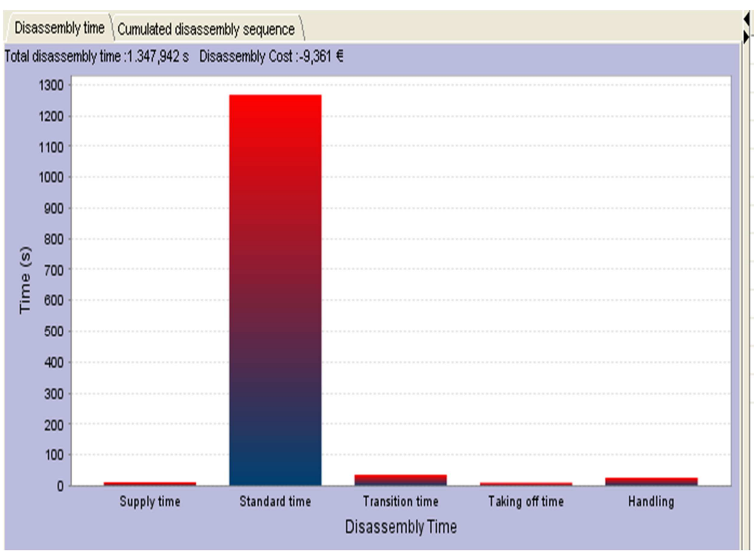


Figure 6-5: Dismantling time breakdown for scenario 2(Source: MAGNA STEYR)

The third step of material flow is the metal separation, in which all the scenarios have the same costs. The fourth step of the material flow is the treatment of non-metallic ASR. The comparison of costs for all scenarios is shown in Table 6-3.

Process Step	Process /Material	Scenario 1 (ISO Simplified)			Scenario 2 (PST VW-SiCon)			Scenario 3 (PST Galloo)		
		costs €/kg	Mass (kg)	Profit/ costs(€)	costs €/Kg	Mass (kg)	Profit/ costs(€)	costs €/kg	Mass (kg)	Profit/ costs(€)
Dismantling[1]	Dismantling cost	-0.88	12.60	-11.09	-1.42	6.60	-9.37			
	prossessing costs	-1.00	12.60	-12.60	-1.00	6.60	-6.60			
	selling price of recycled pellets	0.70	12.60	8.82	0.70	6.60	4.62			
	Total Costs			**-14.87**			**-11.35**			
Metal Seperation[2]	Ferrous metals	0.18	254.80	45.86	0.18	254.80	45.86	0.18	254.80	45.86
	Aluminum	0.30	3.45	1.03	0.30	3.45	1.03	0.30	3.45	1.03
	copper	5.00	12.26	61.28	5.00	12.26	61.28	5.00	12.26	61.28
	Non-ferrous metals	0.65	0.85	0.55	0.65	0.85	0.55	0.65	0.85	0.55
Processing cost for treatment of ASR[3]					0.12	39.95	-4.79	0.12	40.18	-4.82
Energy Recovery of ASR[4]	Cement works	-0.04	38.91	-1.56				-0.04	8.00	-0.32
	Blast furnace				0.04	39.95	1.60	0.04	40.18	1.61
	Total Costs			**-1.56**			**1.60**			**1.29**

Table 6-3: Cost comparison of the scenarios

Processing costs for treatment of ASR is €120/ton. (37) There is no processing cost for treatment of ASR in Scenario 1 because non-metallic ASR is energy recovered in cement works instead of treating for material recycling. The total dismantling process costs for scenario 1 and scenario 2 are quite high and there are no dismantling costs for scenario 3. In terms of economic benefits, the best results are demonstrated by using post-shredder technology of Galloo in scenario 3.

1 Source: Wipag technologies
2 Source: VW-SiCon
3 Source: Information received from BMW
4 Source: Information received from BMW

7 Conclusions

The growth rate of electric cars in segment L7e is expected to be high, so the European Union should prepare a road map to include L7e segment cars in ELV regulation. According to standard ISO 22628:2002, pretreated and dismantled vehicle components are considered to be 100 % recyclable. Therefore the fulfillment of ELV recycling targets for this segment cause no environment benefit, because the mass of the lithium ion battery is approximately one third of the total mass of the electric car. But in contradiction to conventional lead-acid batteries there are no proven technologies to recycle lithium ion batteries at the moment. Additionally continuous alteration in chemical composition of these batteries make the recycling more complicated process. Lithium ion batteries of electric vehicles should be considered to be recyclable according to standard ISO 22628:2002 only if there are available proven recycling technologies. Besides light weight construction should be hindered by ELV legislation.

Energy and material recovery from end-of life vehicles by using post-shredding technologies is essential and has the potential for increased recycling and recovery of non-metallic ASR. It is a step towards more sustainable recycling process that enables economic and ecological benefits. The currently available proven post-shredding technologies have been improved significantly regarding the separation of material fractions for further recycling. Nevertheless many valuable materials especially in electrical and electronic components are still not recovered and lost in landfilling. But the actual problem is that the majority of end-of life vehicles in Europe are not treated by stat-of-the-art recycling technologies but exported to Africa and Asia.

The calculation results show that the post-shredder technologies are not only a necessary solution to fulfill the European recycling quota targets for ELVs, but also a key to better economic recycling benefits compared to dismantling practices

Scenario 1(ISO Simplified), without recycling of non-metallic ASR is the economically worst scenario due to higher costs for dismantling of components in order to meet the legal recyclability target rates. Scenario 2 using PST VW-SiCon technology for recovery of non-metallic ASR allows lowers the dismantling costs due to decreased number of components that have to be dismantled. Besides the output fractions of VW-SiCon technology can lower treatment costs for recovery. VW-SiCon process developed a pilot project to improve the recycling process and to get 99% purity plastics to lower the treatment costs furthermore. Scenario 3 using PST Galloo technology for the treatment of the non-metallic ASR is economically the best recycling solution, because no additional components are required for dismantling due to the post-shredder separation and recycling of polyolefines.

Due to high labor costs for disassembly in Europe, even parts that are designed for disassembly are not removed. Recyclers should think to implement new technologies for further improvements of the separation of plastics from ASR instead of implementing costs on DFD technique. This can be verified by the process comparison of the scenarios 1 & 3. Every year the amount of plastics in interior and exterior application in vehicle is rising. Only improved separation technologies for plastics in the non-metallic ASR and new technologies for recycling of valuable materials in electric and electronic components will contribute to prevent further new materials shortage and will encourage the development of markets for recycled materials. It will help to reduce further global warming and will increase recycling profit for end-of life vehicles.

8 List of Abbreviations

AISC	Automotive Industry Standards Committee
ASR	Automotive Shredder Residue
ATF	Authorized Treatment Facilities
BIS	Bureau of Indian Standards
bhp	Brake horse power
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CoD	Code of Destruction
DFD	Design for Dismantling
DFR	Design for Recycling
ECE	Economic commission of Europe
EEC	European Economic Community
ELV	End of Life Vehicle
EP	European Parliament
ISO	International Organization for Standardization
IHS	internal MAGNA STEYR IMDS system
IMDS	International Material Database System
LCA	Life Cycle Assessment
LPG	Liquid Petroleum Gas
L7e	Homologation category for quadricycles according to directive 2002/24/EC
MILA	MAGNA Innovative Lightweight Auto
MONM	Modified Organic Natural Materials
M1	Homologation category for passenger vehicles according to Directive 70/156/EC
N1	Homologation category for carriage of goods with a maximum mass not exceeding 3.5 tones according to Directive 70/156/EC
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Boards
PVC	Poly vinyl chloride
RRR	Reusability, Recyclability and Recoverability
SIAM	Society of Indian Automotive Manufacturers
TRIZ	Theory of Inventive problem solving (In English)
USGS	United States Geological Survey
WEEE	Waste of Electric Electronic Equipment

9 List of Figures

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11 Bibliography

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12 Appendix

12.1 Appendix-1

Bill Of Material (BOM) of the E-MILA Student

Vehicle Specifications	
Manufacturer	MAGNA STEYR
Project Code	E-Mila Student
Vehicle Type	Micro Car
Vehicle Class	A-
Drive	Battery Electric Vehicle
Production Partners	tbd (PSA, Fiat)
Markets	ECE, Japan, China, USA
Dealer Network	Partner
SOP	08 2012
EOP	08 2019
Model life [years]	7
Units overall	60000
Units 1st year	4000
Units 2nd year	10000
Units 3rd year	10000
Units 4th year	10000
Units 5th year	10000
Units 6th year	10000
Units 7th year	6000
Applies to legal requirements	L7e (Europe)
	FMVSS 500 (USA)
	Kei-Cars (Japan)
Number of trim level	2 (Base, High)
Pricing	
Price with battery [€] BASE	15260
Price w/o battery [€] HIGH	16500
Battery [€]	6200

Technical Specifications	
Drive	
Drive	electric
Type of drive	rear wheel drive
Chassis type	space frame (Al, Steel)
Outer Panels	Through-Colour, recyclable, natural fibres
Recycling Rate [%]	85
Recycling Rate and Recovery [%]	95
Number of Seats	3
Number of Tyres	4
Spare Wheel	No
Vehicle Shape	one box
Number of doors	3
Driver Position	front central
HMI	Steering Wheel, two pedals
Motor	3 Phase Brushless
Cooling	Air
Gearbox	Single Speed
Dimensions	
Height [mm]	1560
Length [mm]	2550
Width [mm]	1475
Wheel base [mm]	tbd
Wheel track front [mm]	1283
Wheel track rear [mm]	tbd
Ground clearance [mm]	80
Overhang rear/front [mm]	50/50
turning cycle left [m]	8
turning cycle right [m]	8
trunk volume [l]	180
Interior with front/rear	1100/1350
Weight	
Vehicle weight without battery [kg]	400
Battery Weight [kg]	160
Curb Weight [kg]	560
Max. Weight kg inc. Bat+ Person + Freight [kg]	950
Weight distribution front/rear [%]	tbd
Tyres	
Tyres	145/70 R13
Driving Performance	
Power [kW]	15
Torque [Nm]	tbd
Top Speed [kph]	85

Top Speed limited USA [kph]	56
Acceleration 0-50 km/h [s]	6
Acceleration 0-80 km/h [s]	tbd
Range (including all electric auxiliaries) [km]	90
Battery	
Battery type	Lithium Ion
Battery Capacity [kWh]	15
Battery Power	tbd
Battery Supplier	MAGNA E-Car Systems
Battery warranty [years]	3
Battery warranty [km]	70000
Battery life cycle [km]	150000
Recharge time full [h]	6
Recharge time 80% fast charge [h]	0.75
Charging methods on board	normal + fast 3 phase
Battery self-discharge	-3% less autonomy per week

12.2 Appendix-2

PartName	Quantity	Module mass (Kg)	Part Mass	Total mass (Kg)	Material Mass (Kg)	Material Category according to VDI231-106
Body		**77.0**				
Space Frame	1		75	75.00	75.00	Steel and Iron Materials
Painting	1		2	2.00	2.00	Process Polymers
FrontBumper		**5.2**				
Front Bumper Strucutre	1		2.2	2.20	2.20	Steel and Iron Materials
Front bumper	1		2.5	2.50	2.45	Polymer materials
					0.05	Polymer materials
Wheel arch trim	2		0.2	0.40	0.40	Polymer materials
Wheel arch cap	2		0.05	0.10	0.10	Polymer materials
Rear Bumper		**4.8**				
Rear Bumper Strucutre	1		2	2.00	2.00	Steel and Iron Materials
Rear bumper	1		2.3	2.30	2.25	Polymer materials
					0.05	Polymer materials
Wheel arch trim	2		0.2	0.40	0.40	Polymer materials
Wheel arch cap	2		0.05	0.10	0.10	Polymer materials
Exteriors		7.3				
Front Fender outer Right/Left	2		1.2	2.40	2.40	Polymer materials
Screws	12		0.01	0.12	0.12	Steel and Iron Materials
C-Pillar trim outer	2		1.2	2.40	2.40	Polymer materials
D pillar panel outer uppper L/R	2		1.2	2.40	2.40	Polymer materials
wiping and Washing system	**1**	**2.0**				
Wiping motor	1		0.9	0.90	0.90	Electronics/Electrics
Wiper blade	1		0.3	0.30	0.25	Polymer materials
					0.05	Polymer materials
Front wiper relay system	1		0.1	0.10	0.10	Electronics/Electrics
Wiper linkage	1		0.7	0.70	0.70	Steel and Iron Materials
Interiors						
Overhead-Module		**2.1**				
Headliner	1		1	1.00	0.30	Polymer materials
					0.40	Polymer materials
					0.30	Polymer materials
Grab handle	2		0.17	0.34	0.34	Polymer materials
sunvisor	2		0.4	0.80	0.80	Polymer materials
Pillar trims	**2**	**5.4**				
A-pillar trim	2		0.25	0.50	0.50	Polymer materials

B-Pillar trim	2		0.25	0.50	0.50	Polymer materials
C-Pillar trim	2		0.2	0.40	0.40	Polymer materials
Sill cover	2		0.3	0.60	0.60	Polymer materials
Rear Cover panels	2		0.7	1.40	1.40	Polymer materials
Carpets and mats	2		1	2.00	2.00	Polymer materials
Cockpit Module		**9.0**				
Dashboard Strucutre	1		4.7	4.70	4.50	Steel and Iron Materials
Dashboard panel	1		3	3.00	3.00	Polymer materials
Steering Column over	1		0.3	0.30	0.30	Polymer materials
Glove box	1		1	1.00	1.00	Polymer materials
Front seats FS / FSO		**8.6**				
Front seat frame+track	1		5.7	5.70	5.70	Steel and Iron Materials
Seat cushion trim	1		0.2	0.20	0.20	Polymer materials
Seat cushion foam	1		0.8	0.80	0.80	Polymer materials
Seat back trim	1		0.3	0.30	0.30	Polymer materials
Seat back foam	1		0.7	0.70	0.70	Polymer materials
brackets	3		0.3	0.90	0.90	Polymer materials
Rear seats		**17.2**				
Rear seat frame+track	2		5.7	11.40	11.40	Steel and Iron Materials
Seat cushion trim	2		0.2	0.40	0.40	Polymer materials
Seat cushion foam	2		0.8	1.60	1.60	Polymer materials
Seat back trim	2		0.3	0.60	0.60	Polymer materials
Seat back foam	2		0.7	1.40	1.40	Polymer materials
Atatchment Bolts and bracke	6		0.3	1.80	1.80	Steel and Iron Materials
Belt assy, front / rear		**3.1**				
Safety belt complete	3		0.8	2.40	1.45	Steel and Iron Materials
					0.95	Polymer materials
Lock	3		0.2	0.60	0.10	Steel and Iron Materials
					0.50	Polymer materials
Bezel	3		0.03	0.09	0.09	Polymer materials
Closures						
Bonnet compl.		3.1				
Trim hood	1		1.8	1.80	1.80	Polymer materials
Latch	1		0.8	0.80	0.80	Steel and Iron Materials
sealings	1		0.5	0.50	0.50	Process Polymers
Doors		**36.1**				
Front door Structure left / right	2		5	10.00	10.00	Steel and Iron Materials
Assy panel Door	2		2.4	4.80	4.80	Polymer materials

Inner+Outer						
sealings	2		0.5	1.00	0.50	Process Polymers
Door Glass	4		1.2	4.80	4.80	Polymer materials
Trunklidstucture	1		5	5.00	5.00	Steel and Iron Materials
Tailgate outer pannel	1		1.2	1.20	1.20	Polymer materials
Tailgate inner pannel	1		0.8	0.80	0.80	Polymer materials
Front Windshield	1		4.5	4.50	4.50	Other materials and material compounds
Rear Windshield	1		4	4.00	4.00	Other materials and material compounds
Axle						
Front axle complete		**40.6**				
Knuckle left	1		3	3.00	3.00	Steel and Iron Materials
Knuckle right	1		3	3.00	3.00	Steel and Iron Materials
Wheel Hub Bearing	2		1	2.00	2.00	Steel and Iron Materials
Wishbone	1		2	2.00	2.00	Steel and Iron Materials
Wishbone	1		2	2.00	2.00	Steel and Iron Materials
Brakedisk	2		3	6.00	6.00	Steel and Iron Materials
Calliper	2		2.9	5.80	5.80	Steel and Iron Materials
Brake Pads	4		0.2	0.80	0.80	Process polymers
Assy Suspension Strut	1		6.5	6.00	6.00	Steel and Iron Materials
Assy Suspension Strut	1		6.5	6.00	6.00	Steel and Iron Materials
Anti Roll Bar	1		4	4.00	4.00	Steel and Iron Materials
Assy Twist Beam Axle	**1**	**32.8**				
Weld Assy Twist Beam Axle	1		10	10.00	10.00	Steel and Iron Materials
Wheel Bearing	2		0.5	1.00	1.00	Steel and Iron Materials
Wheel Hub	2		1	2.00	2.00	Steel and Iron Materials
Spring	2		0.7	1.40	1.40	Steel and Iron Materials
Damper	2		2	4.00	4.00	Steel and Iron Materials
Brake Drum	2		2.3	4.60	4.60	Steel and Iron Materials
Brake Shield	2		0.3	0.60	0.60	Steel and Iron Materials
Assy Drive Shaft	1		4.5	4.50	4.50	Steel and Iron Materials
Assy Drive Shaft	1		4.5	4.50	4.50	Steel and Iron Materials
Nut M16x1,5 (Drive Shaft)	2		0.01	0.02	0.02	Steel and Iron Materials
Screw M6	8		0.01	0.08	0.08	Steel and Iron Materials
Screw M8	8		0.01	0.08	0.08	Steel and Iron Materials
Screw M10	2		0.01	0.02	0.02	Steel and Iron Materials

Electric Drive Rear Axle		**40.0**				
Electric Motor	1		25	25.00	25.00	Electronics/Electrics
Gear Box i=8	1		15	15.00	8.50	Steel and Iron Materials
					6.47	Steel and Iron Materials
					0.01	Polymer materials
					0.02	Polymer materials
Battery Assy	**1**	**150**				
Battery Frame	1		30	30.00	30.00	Polymer materials
Battery Module 8 Cells	5		24	120.00	120.00	Electronics/Electrics
Radiator assy		3.0				
Radiator	1		1	1.00	1.00	Polymer materials
Coolant	1		2	2.00	2.00	Fuels and Auxilary means
Steering ,Wheels & HVAC						
Steering System		**12.0**				
Rack and Pinion Steering	1		5	5.00	5.00	Steel and Iron Materials
Tie Rod	2		1	2.00	2.00	Steel and Iron Materials
Steering Column	1		5	5.00	5.00	Steel and Iron Materials
HV Components	**1**	**17.1**				
Inverter	1		6.5	6.50	6.50	Fuels and Auxilary means
Charger 3,3kW	1		6	6.00	6.00	Electronics/Electrics
DC/DC Converter 600W	1		2.5	2.50	2.50	Electronics/Electrics
HV Cable	10		0.21	2.10	2.10	Electronics/Electrics
Wheels / Tyres ink. Assembly and the temporary spare wheel		**42.0**				
Tire Front 135/80 R13	2		10	20.00	9.50	Steel and Iron Materials
					10.15	Polymer materials
					0.35	Polymer materials
Tire Rear 175/70R13	2		10.5	21.00	9.90	Steel and Iron Materials
					10.75	Polymer materials
					0.35	Polymer materials
Bolt	12		0.08	0.96	0.96	Steel and Iron Materials
Bordausruestung (tool kit), jack		**0.4**				
Towing assembly	2		0.2	0.40	0.40	Steel and Iron Materials
Brake System		**7.8**				
Master Braking Cylinder	1		0.5	0.50	0.50	Steel and Iron Materials

all brake lines	1		1.5	1.50	1.50	Steel and Iron Materials
Assy Hand Brake Lever	1		2.8	2.80	2.80	Steel and Iron Materials
ABS System	1		3	3.00	3.00	Steel and Iron Materials
PEDALBLOCK +BREMSPEDAL		**2.0**				
Accelerator pedal	1		0.5	0.50	0.50	Polymer materials
Brake pedal	1		1.5	1.50	1.50	Steel and Iron Materials
Electrical / Electronics		**21.0**				
Lights	1		6	6.00	6.00	Electronics/Electrics
Ld Acid Battery	1		7	7.00	7.00	Fuels and Auxilary means
Electronic Control Unit	1		0.5	0.50	0.50	Electronics/Electrics
Wiring Harness	1		7.5	7.50	7.50	Electronics/Electrics
Total Vehicle Mass		**549.6**				

12.3 Appendix-3

Data presentation
ISO 22628:2002

MAGNA STEYR

Brand name:	Magna Steyr	Vehicle mass, mV:	399,7 kg
Model (type/ variant):	Student EMILA		

Materials Breakdown	Metals	Polymers (exl. elastomers)	Elastomers	Glass	Fluids	MONM	Others
	Mass (Kg)						
	298,8	56	17,6	8,8	6,4	0	12,1

Pretreatment (mp)			Mass (kg)
	Fluids	mp1	5,9
	Battery	mp2	7,5
	Oil filters	mp3	0
	LPG tanks	mp4	0
	CNG tanks	mp5	0
	Tyres	mp6	41,2
	Catalytic converters	mp7	0
		mp total (sum mp1 to mp7) =	54,6

Dismantling (mD)

Part Number	Name	Mass (Kg)	Part Number	Name	Mass (Kg)	Mass (part 11 to 30) (kg)	
1	Front bumper	2,5	6	SEATBELT	1	mD30	9,7
2	Rear bumper	2,3	7	SEATBELT	1		
3	Assy trim	1,2	8	SEATBELT	1		
4	Tailgate outer	1,2	9	Rear Seat	0,8		
5	Assy trim	1,2	10	Rear Seat	0,8		
mD1 total (sum 1 to 5)		8,4	mD2 total (sum 6 to 10)		4,7	mD total (mD1 + mD2 + mD30) =	22,8

Metal separation (mM)	Remaining vehicle metallic content:	Mass (Kg)	
		mM=	268,6

Non-metallic residue treatement (mTr and mTe)				
	Recyclable materials (mTr)			Mass (Kg)
	Technology no.	Name		
	1		mTr1	
	2		mTr2	
	3		mTr3	
			mTr total (sum mTr1 to mTr0	0
	Energy recoverable materials (mTe)			Mass (Kg)
	Remaining quantity of organic materials (polymers, elastomers etc.):		mTe =	32,9

Recyclability rate	Rcyc = [(mP + mD + mM + mTr) / mV] x100	87 %
Recoverability rate	Rcov = [(mP + mD + mM + mTr + mTe) / mV] x100	95 %

Recyclability and recoverability calculations of E-MILA Student vehicle by ISO Simplified scenario

Data presentation
ISO 22628:2002

MAGNA STEYR

Brand name:	Magna Steyr			Vehicle mass, mV:			399,7 kg
Model (type/ variant):	Student EMILA						
Materials Breakdown	Metals	Polymers (exl. elastomers)	Elastomers	Glass	Fluids	MONM	Others
	Mass (Kg)						
	298,8	56	17,6	8,8	6,4	0	12,1

Pretreatment (mp)			Mass (kg)
	Fluids	mp1	5,9
	Battery	mp2	7,5
	Oil filters	mp3	0
	LPG tanks	mp4	0
	CNG tanks	mp5	0
	Tyres	mp6	41,2
	Catalytic converters	mp7	0
		mp total (sum mp1 to mp7) =	54,6

Dismantling (mD)							
Part Number	Name	Mass (Kg)	Part Number	Name	Mass (Kg)	Mass (part 11 to 30) (kg)	
1	Front bumper	2,5	6	SEATBELT	1	mD30	9,7
2	Rear bumper	2,3	7	SEATBELT	1		
3	Tailgate outer	1,2	8	SEATBELT	1		
4	Assy trim	1,2	9	Front Seat	0,8		
5	Assy trim	1,2	10	Rear Seat	0,8		
mD1 total (sum 1 to 5)		8,4	mD2 total (sum 6 to 10)		4,7	mD total (mD1 + mD2 + mD30) =	22,8

Metal separation (mM)		Mass (Kg)
	Remaining vehicle metallic content:	mM= 269

Non-metallic residue treatement (mTr and mTe)	Recyclable materials (mTr)			Mass (Kg)
	Technology no.	Name		
	1	Thickner for sewage sludge	mTr1	2
	2	Vinyloop Ferrara	mTr2	0
	3	Thickner for sewage sludge	mTr3	0
			mTr total (sum mTr1 to mTr3	2,1
	Energy recoverable materials (mTe)			Mass (Kg)
	Remaining quantity of organic materials (polymers, elastomers etc.):		mTe =	31,9

Recyclability rate	Rcyc = [(mP + mD + mM + mTr) / mV] x100	87 %	
Recoverability rate	Rcov = [(mP + mD + mM + mTr + mTe) / mV] x100	95 %	

Recyclability and recoverability calculations of E-MILA Student vehicle by VW-SiCon recycling scenario

Data presentation
ISO 22628:2002

MAGNA STEYR

Brand name:	Magna Steyr				Vehicle mass, mV:		399,7 kg
Model (type/ variant):	Student EMILA						
Materials Breakdown	Metals	Polymers (exl. elastomers)	Elastomers	Glass	Fluids	MONM	Others
	Mass (Kg)						
	298,8	56	17,6	8,8	6,4	0	12,1
Pretreatment (mp)					Mass (kg)		
	Fluids			mp1	5,9		
	Battery			mp2	7,5		
	Oil filters			mp3	0		
	LPG tanks			mp4	0		
	CNG tanks			mp5	0		
	Tyres			mp6	41,2		
	Catalytic converters			mp7	0		
					mp total (sum mp1 to mp7) =		54,6
Dismantling (mD)							
Part Number	Name	Mass (Kg)	Part Number	Name	Mass (Kg)	Mass (part 11 to 36) (kg)	
1	RR WINDOW	4,7	6	Assy trim	1,2	mD36	15
2	Wind Shield	4,5	7	Assy trim	1,2		
3	Front bumper	2,5	8	Front Door	1,2		
4	Rear bumper	2,3	9	Front Door	1,2		
5	Tailgate outer	1,2	10	SEATBELT	1		
mD1 total (sum 1 to 5)		15,2	mD2 total (sum 6 to 10)		5,8	mD total (mD1 + mD2 + mD36) =	36
Metal separation (mM)	Remaining vehicle metallic content:					Mass (Kg)	
						mM=	269
Non-metallic residue treatement (mTr and mTe)	Recyclable materials (mTr)					Mass (Kg)	
	Technology no.	Name					
	1	Galloo Plastics			mTr1	15,3	
	2				mTr2		
	3				mTr3		
						mTr total (sum mTr1 to mTr1	15,3
	Energy recoverable materials (mTe)					Mass (Kg)	
	Remaining quantity of organic materials (polymers, elastomers etc.):					mTe =	14,2
	Recyclability rate		Rcyc = [(mP + mD + mM + mTr) / mV] x100			94 %	
	Recoverability rate		Rcov = [(mP + mD + mM + mTr + mTe) / mV] x100			97 %	

Recyclability and recoverability calculations of E-MILA Student vehicle by Gallo recycling scenario