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Design for Recycling in the Transport Sector – Future Scenarios and Challenges

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Summary

The objectives of the project are to:

- make a survey of the recycling system and market in Europe;
- present scenarios of future recycling systems and markets;
- suggest design guidelines in order to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials, and increase the recycling rate.

The report includes a description of end-of-life treatment of vehicles (focus on automobiles) in Europe today and options for the future. Four different scenarios for future recycling systems are presented for the years 2015 and 2030. The scenarios are *no predictions* of the future recycling system but descriptions of *potential* recycling systems based on certain assumptions, such as technology development of recycling processes. Relevant design guidelines for recycling are suggested based on these scenarios. Some characteristics for the design guidelines are that:

- materials and components including hazardous substances should primarily be avoided or otherwise be labelled and designed for disassembly, for example, to increase the quality of material fractions for recycling and energy recovery;
- PVC and copper should either be dismantled or be avoided in components that are not dismantled, for example in electrical cables, to increase the quality of material fractions for recycling and energy recovery;
- additional design for disassembly is usually unnecessary except for some few materials and components in a dismantling optimistic scenario, i.e. large parts of monomaterials or more valuable materials;
- the choice of plastics, including their additives and coatings, should be made to increase the quality and demand of recycled plastics;
- few or none guidelines for recycling are needed when assuming best available technology.

Keywords: Design for Recycling, design guidelines, recycling, transport sector, automobiles, rail vehicles, trucks, scenarios

Extended summary

The aim of the project is to increase the knowledge for the transport sector's mechanisms that control how their discarded products are recycled. This knowledge can make it possible for the industry to develop more resource saving products and to get control of their costs related to producer responsibility. Furthermore, the aim is to contribute towards a common picture of the future for the manufacturing industry and recycling industry, which can increase the possibilities for the recycling industry of long term planning and investment in new processing techniques and facilitate for manufacturing industries to design for recycling.

The objectives of the project are to:

- make a survey of the recycling system and market in Sweden and Europe;
- present scenarios of future recycling systems and markets;
- suggest design guidelines in order to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials, and increase the recycling rate.

In this project, we focus on automobiles.

A large amount of vehicles is manufactured and scrapped in the European Union every year. The production implies a large demand of resources, and the end-of-life vehicle (ELV) treatment results in a large amount of residues, which up to now has been put on landfill.

Recycling of materials is a strategy that can be used to:

- increase the availability of resources, which is especially important for scarce resources;
- reduce emissions, for example, leakage of hazardous substances from landfills to atmosphere and groundwater;
- reduce the need of space for landfill.

A demand of an increased recycling of vehicles comes both from the society and from customers. Producer's responsibility is introduced within many lines of business today. The European end-of-life vehicle (ELV) directive (2000/53/EC) has set forward requirements on how much of the materials in an ELV that has to be reused or recycled, how much that can be incinerated for energy recovery, and the maximum amount that can be put to landfill by the years 2006 and 2015. Similar requirements are also present for other vehicles in the transport sector and to increase the recoverability and recyclability rates are relevant for larger vehicles as well. In this report, we summarize some relevant laws and regulations for ELVs.

When developing products today, product designers do not only have to take the cost and material performance into account but also the recyclability and the environmental performance such as energy use of the products. There exists a large amount of design guidelines for recycling, and also tools and methods for design for recycling (DfR) and design for environment (DfE). Design guidelines for recycling can include choices of materials and material combinations as well as joining of different components.

However, a lifetime over several decades of vehicles, for example, up to 20-30 years for an automobile, implies difficulties and a great challenge in integrating the ELV directive into product development. The long lifetime implies uncertainties about the future recycling system, such as technologies and costs, and about the future demand of recycled materials. A strategy to increase the demand of recycled materials is to increase the quality of recycled materials. Another strategy is to use recycled materials in the own manufacturing. Accessible information about how the future recycling systems may be structured can together with recycling values for materials enable the product designer to account for these issues. The relevance of design guidelines for recycling can be improved by considering the expected lifetime of products and the potential end-of-life treatment for these products. Different sets of design guidelines for recycling are relevant for different future recycling systems.

In the report, we give a state of the art report about ELV treatment for the transport sector in Sweden and Europe. It covers the situation today and describes development trends for the future. Various materials output fractions of the different operations and following recycling/recovery options are described. Some technical, economic, and environmental aspects are also considered. Different recycling options for materials are described, and material qualities and some potential applications of recycled materials are discussed.

The ELV treatment can be described as a four-step-process. The four steps are pre-treatment, dismantling, shredding, and shredder residue (SR) treatment. There are different options to increase the recycling and recovery quotas compared to today, and hence different potential future recycling systems. There are two main strategies to fulfil the requirements of recovery and recycling quotas set up in the ELV directive, either to extend the dismantling of parts or to use some of the SR treatment technologies. As the dismantling is costly, the focus at the moment is on evaluating the available SR treatment technologies from economical, technical, and environmental point of views.

Four different scenarios for future recycling systems for end-of-life vehicles (automobiles) in Europe are presented for the years 2015 and 2030. A large part of the ELVs in 2015 are the automobiles that are manufactured today, and the ELVs in 2030 are the automobiles that are designed today. The year 2030 also represents a year when more comprehensive changes of the recycling system have had time to occur.

The scenarios are *no predictions* of the future recycling system but descriptions of *potential* recycling systems based on certain assumptions, such as technology development of recycling processes. The choice of scenarios is made to reflect a wide range of potential recycling systems. Manufacturing industries can choose to consider all potential scenarios, or to reject some scenarios.

The four scenarios are:

1. *Business as usual*, years 2015 and 2030, in which we assume a moderate technical development of recycling processes.
2. *Dismantling*, year 2030, in which we assume that several components will be dismantled for recycling before shredding.
3. *Best available technology*, year 2030, in which we assume a significant technical development of recycling processes, i.e. shredder processes and processes for pre-treatment of shredder residues.
4. *Energy recovery*, year 2030, in which we assume that a larger share of energy recovery is accepted compared to the present ELV directive.

In the report, relevant design guidelines for recycling are suggested based on these four scenarios of future recycling systems. The choice and priority of design guidelines for recycling can be facilitated if they are combined with motives, such as:

- to increase the recycling or recovery quota;
- to facilitate and reduce costs for pre-treatment or dismantling;
- to increase the quality and demand of recycled materials.

Some characteristics for the design guidelines based on the scenarios in this report are that:

- materials and components including hazardous substances (for example, mercury, lead, cadmium, and fluids) should primarily be avoided or otherwise be labelled and designed for disassembly, for example, to increase the quality of material fractions for recycling and energy recovery;
- PVC and copper should either be dismantled or be avoided in components that are not dismantled, for example in electrical cables, to increase the quality of material fractions for recycling and energy recovery;
- additional design for disassembly is usually unnecessary except for some few materials and components in a dismantling optimistic scenario, i.e. large parts of monomaterials or more valuable materials;
- the choice of plastics, including their additives and coatings, should be made to increase the quality and demand of recycled plastics;
- few or none guidelines for recycling are needed when assuming best available technology.

There is today several design for environment guidelines available, within manufacturing industries, which can be considered by designers at the product development process. A large part of them promote recycling. Design guidelines are developed and suggested by researchers, manufacturing industries, and recycling industries, which may have different motives for design for recycling. Different guidelines have also been developed at different times under different conditions and based on different knowledge, for example, concerning technology development of recycling processes and market of recycled materials.

We propose that vehicle industries revise their existing guidelines according to relevant scenarios of future recycling systems. They can consider which design guidelines that are to be rejected, that are missing, or should be complemented with information.

Design guidelines can be *rejected* if they are not considered relevant for any recycling system or if they are relevant only for some recycling system that is rejected by the manufacturing industry. Good contact between manufacturing and recycling industries can facilitate a common picture of the future recycling system and thus facilitate the identification of relevant design guidelines for recycling. The future recycling system also depends on the society's future requirements on recycling, for example, compared to requirements on reduced emissions of green house gases and on preserved material quality of recycled materials.

Design guidelines, as they stand alone, often need some *complementary information* to be useful for designers, which should be based on conditions in potential future recycling systems. Examples of complementary information are which materials are recyclable or compatible with each other, which materials and components should be designed for disassembly, and specified information on how materials and components should be joined to facilitate separation at shredding. In this context, we recommend:

- a continued work on formulating a common definition on material recycling and energy recovery;
- a standardised system for the transport sector for labelling and identification of components including hazardous substances.

Examples of design guidelines that can be *missing* are:

- choice of plastics (based on their densities) to facilitate separation at SR treatment and to increase the quality and demand of recycled metals;
- choice of metal alloys to increase the quality and demand of recycled metals, for example, avoid rare alloying elements that can reduce the quality of other alloys.

Foreword

This is the final report in the project *Design for Recycling*. The project has been accomplished at *Chalmers University of Technology* in Göteborg and at companies connected to the *Centre for Environmental Assessment of Product and Material Systems* (CPM) at Chalmers. There have also been consultants involved in the project. The project started in December 2002 and was ended in August 2004.

Ulrika Lundqvist at the department of Physical Resource Theory at Chalmers has been the project leader. Additional participants have been:

- Peter Forsberg at Mechatronics division, Chalmers University of Technology, Göteborg
- Ulf Liljenroth at WSP Environmental, Göteborg, and
- Karin Strömberg at CIT Ekologik, Göteborg.

The participating companies have been (in the order of their contribution):

- SAAB Automobile, Trollhättan: Britt Andersson, Maria Axsäter, and Ulf Jonson;
- Volvo Car Corporation, Göteborg: Andreas Andersson, Elisabeth Dahlqvist, and Caroline Sjöberg (Volvo Technology);
- AB Volvo, Göteborg: Katarina Heikkilä (Volvo Technology), Patrik Klintbom (Volvo Technology), and Marcus Wendin (Volvo Technology);
- Bombardier Transportation, Västerås: Ylva Larsson;
- Akzo Nobel, Stenungsund: Anastasia Manuilova.

There is an additional report in this project (not included in this report):

- Anastassia Manuilova, 2003. Life Cycle Assessment of industrial packaging of chemicals. Akzo Nobel, Stenungsund.

All participants in the project have contributed to the results and conclusions presented in this report. There have been several meetings when we have shared information and had interesting discussions. The project has resulted in several documents of which most are included in the Appendices and this report is partly based on these documents. Ulrika Lundqvist has edited the whole report. There are several authors to the report, and their individual contributions are described below.

1. Introduction
Ulrika Lundqvist is the main author.

2. Laws and regulations
Is based on Axsäter [2004] and Sjöberg [2004b] in Appendices A and B. Ulf Liljenroth and Ulrika Lundqvist are the authors to some parts of the text.

3. The end-of-life treatment of automobiles
Is based on Sjöberg [2003], Andersson and Jonson [2004], and Liljenroth [2004] in Appendices C, D, and E. Ulrika Lundqvist is the author to some parts of the text.

4. The end-of-life treatment of trucks and rail vehicles
The section on trucks is based on Wendin [2003], in Appendix G, and is edited by Ulrika Lundqvist together with Katarina Heikkilä. Ylva Larsson is the author to the section on rail vehicles, based on Larsson [2004a] in Appendix F.

5. Recycling of materials and the material market
Karin Strömberg is the main author. Maria Axsäter is the author to section 5.4 on thermoplastics and Ulrika Lundqvist to the introduction. Some relevant information can be found in Sjöberg [2003a], Wendin [2003], Larsson [2004b] and Sjöberg [2004a], in Appendices G, H, I, and J.

6. Scenarios of future recycling systems
Britt Andersson, Ulf Liljenroth, and Ulrika Lundqvist are the authors to the sections on scenarios. Katarina Heikkilä and Ylva Larsson are the authors to section 6.7 on trucks and rail vehicles.

7. Design guidelines for recycling
Ulrika Lundqvist is the main author. Katarina Heikkilä and Ylva Larsson have contributed to the analysis of existing design guidelines based on scenarios. Section 7.3 on economic optimisation of the recycling system is based on Forsberg [2004] in Appendix L.

8. Discussion
Ulrika Lundqvist is the main author.

9. Conclusions
Ulrika Lundqvist is the main author.

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B. Caroline Sjöberg, 2004. Trends in society concerning waste treatment and producer responsibility. Volvo Car Corporation, Göteborg

C. Britt Andersson and Ulf Jonson, 2004. ELV treatment. SAAB Automobile, Trollhättan

D. Ulf Liljenroth, 2004. Shredder technology – Development and trends in Europe. WSP Environmental, Göteborg

E. Caroline Sjöberg, 2003. Post-shredder treatment technologies. Volvo Technology Corporation, Göteborg

F. Ylva Larsson, 2004. Bombardier Transportation experiences of end of life treatment of rail vehicles. Bombardier Transportation, Västerås

G. Marcus Wendin, 2003. End of life for trucks in Europe and material recycling. Volvo, Göteborg

H. Caroline Sjöberg, 2003. Material: Glass. Volvo Car Corporation, Göteborg

I. Caroline Sjöberg, 2004. Material: PVC. Volvo Car Corporation, Göteborg

J. Ylva Larsson, 2004. Recycling information about different composites. Bombardier Transportation, Västerås

K. Katarina Heikkilä, 2004. Hazardous substances in materials of trucks. Volvo, Göteborg

L. Peter Forsberg, 2004. Recycling profitability optimisation using genetic algorithms. Mechatronics division, Chalmers University of Technology, Göteborg

1 Introduction

A large amount of vehicles is manufactured and scrapped in the European Union every year. The production implies a large demand of resources, and the end-of-life vehicle (ELV) treatment results in a large amount of residues, which up to now has been put on landfill.

Recycling of materials is a strategy that can be used to:

- increase the availability of resources, which is especially important for scarce resources;
- reduce emissions, for example, leakage of hazardous substances from landfills to atmosphere and groundwater;
- reduce the need of space for landfill.

A demand of an increased recycling of vehicles comes both from the society and from customers. Producer's responsibility is introduced within many lines of business today. The European end-of-life vehicle (ELV) directive (2000/53/EC) has set forward requirements on how much of the materials in an ELV that has to be reused or recycled, how much that can be incinerated for energy recovery, and the maximum amount that can be put to landfill by the years 2006 and 2015. Similar requirements are present also for other vehicles in the transport sector, and to increase the recoverability and recyclability rates are relevant for larger vehicles as well.

When developing products today, product designers do not only have to take the cost and material performance into account but also the recyclability and the environmental performance, such as energy use, of the products. There exists a large amount of design guidelines for recycling, and also tools and methods for design for recycling (DfR) and design for environment (DfE). Design guidelines for recycling can include choices of materials and material combinations as well as joining of different components.

However, a lifetime over several decades of vehicles, for example, up to 20-30 years for an automobile, implies difficulties and a great challenge in integrating the ELV directive into product development. The long lifetime implies uncertainties about the future recycling system, such as technologies and costs, and about the future demand of recycled materials. How is it possible for a designer to meet the demands of the ELV directive without too large costs for the end-of-life treatment of the vehicle?

A strategy to reduce costs for the ELV treatment is to increase the value of the recycled materials, which depends on the demand of the recycled materials. The demand can be increased if the manufacturing industries use recycled materials in their own manufacturing and, related to this issue, if the quality of recycled materials is improved. The quality of recycled materials depends on the recycling processes but also on the design of products, i.e. material choices and joining of components. The economic value of recycled materials, i.e., the recycling value, can be used as a measure of material quality.

In the VARM model (Valuation of Recycled Material), a material is divided into several recycling classes [Strömberg, 2000; Strömberg *et al.*, 2002]. This is to resemble the classification of scrap into different classes made by the recycling industry, classes which reflect both the technical and the economic value of the materials. Recycling values for a set of recycling classes for different materials can be used at design for recycling. Information on resulting recycling classes from different recycling processes, such as manual dismantling and shredding, can be integrated in the decisions on choices of materials and design of the product in the product development. The integration of recycling values in LCA gives the designer an incentive to use recycled materials as raw materials and to design products to give high materials recycling values at waste handling.

Scenarios of potential future recycling systems for ELV treatment can be used in the product development as a base for design for recycling, in which the expected lifetime of products is considered. The scenarios should, for example, be based on assumptions about technology development and on future laws and regulations. Different sets of design guidelines for recycling can be relevant for different future recycling systems.

1.1 Aim and objectives

The aim of the project is to increase the knowledge for the transport sector's mechanisms that control how their discarded products are recycled. This knowledge can make it possible for the industry to develop more resource saving products and to get control of their costs related to producer responsibility. Furthermore, the aim is to contribute towards a common picture of the future for the manufacturing industry and recycling industry, which can increase the possibilities for the recycling industry of long term planning and investment in new processing techniques and facilitate for manufacturing industries to design for recycling.

The objectives of the project are to:

- make a survey of the recycling system and market in Sweden and Europe;
- present scenarios of future recycling systems and markets;
- suggest design guidelines in order to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials, and increase the recycling rate.

1.2 Delimitations

The main focus in this report is on automobiles. Rail vehicles and trucks are considered only to some minor extent, but it is assumed that most of the results for automobiles are applicable also to these larger vehicles.

The report does not include an analysis of whether recycling is the best strategy or not to improve the environmental performance. Such analyses can be carried out, for example, within Design for Environment.

The focus is on the content of design guidelines. We do not consider how this information could be integrated in the product development processes since different tools for product development can be used in different companies

1.3 Structure of the report

As a background to the analyses in this project, we summarize some relevant laws and regulations for ELVs and some future trends in Section 2. Furthermore, a state of the art report about ELV treatment for the transport sector in Europe in given in Sections 3 and 4, including development trends for the future. These sections are continued with a description of different recycling options for materials and their resulting material qualities and some potential material applications in Section 5.

Four scenarios of potential future recycling systems for ELV treatment are presented in Section 6. The scenarios are based on certain assumptions, such as technology development of recycling processes. Relevant design guidelines for recycling are suggested based on these scenarios in Section 7. Finally, the report ends with a discussion and some conclusions and recommendations in Sections 8 and 9.

The content of this report is partly based on the content in the appendices, which are included in a separate report. The appendices also include some additional and more detailed information, for example, about actors and companies involved in ELV treatment and recycling of materials.

2 Laws and regulations – Related to the recycling of end-of-life vehicles and influencing the market of recycled materials

In this section, we present some laws and regulations that are related to the recycling of ELVs. The laws and regulations concern the real and potential re-use, recycling, and recovery and they concern recycling criteria for specific components and materials. Towards the end of the section, we also present some future trends. More information on laws and regulations can be found in Axsäter [2004] and Sjöberg [2004b] in Appendices A and B.

The laws and regulations affect:

- the composition of the recycling system;
- the design of vehicles; and
- the supply of recycled materials, both quantity and quality.

The European ELV directive has and will have a significant influence on all these aspects, not at least on the market of recycled materials.

Relevant to know about the European Community law is that it is an independent legal system that takes precedence over national legal provisions. Community law can, for example, take the following forms:

- *Directives* bind Member States as to the objectives to be achieved within a certain time limit while leaving the national authorities the choice of form and means to be used. Directives have to be implemented in national legislation in accordance with the procedures of the individual Member States.
- *Decisions* are binding in all their aspects for those to whom they are addressed. Thus, decisions do not require national implementing legislation. A decision may be addressed to any or all Member States, to enterprises or to individuals.

2.1 Real and potential re-use, recycling, and recovery

The *ELV directive* (2000/53/EC) of the European Parliament and of the Council was published in the autumn of 2000. The main objective of the directive is the prevention of waste from vehicles, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles and especially the operators directly involved in the treatment of end-of life vehicles. The directive includes issues on reuse, recycling, and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste. The directive is valid only for light vehicles (automobiles) and not for heavy vehicles (trucks and rail vehicles).

The ELV directive contains targets for how much of the materials from the ELVs that have to be re-used, recycled, and recovered, according to the following definitions.

- *Reuse* means any operation by which components of end-of life vehicles are used for the same purpose for which they were conceived.
- *Recycling* means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery.
- *Energy recovery* means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat.
- *Disposal* means any of the applicable operations provided for in Annex IIA to Directive 75/442/EEC on waste (see Annex II in Appendix A in this report).

According to the ELV directive, at the minimum 85 % of the vehicle weight shall be recovered or re-used and at the minimum 80 % of the vehicle weight shall be recycled or re-used in 2006. For 2015, the targets are 95 % respectively 85 %. In Sweden, there is a *producer responsibility for vehicles* (SFS 1997:788) since 1998. It includes the recovery quotas (including re-use) of 85 % already in 2002 and 95 % in 2015. There are no recycling quotas. These quotas correspond to the real life ELV treatment and they are tracked in so called *monitoring*.

Most EU countries have today established a monitoring procedure where the amounts of materials for re-use, recovery, and recycling are tracked and reported. These processes are similar but not identical and can be more or less complicated. Work is done by the Waste Technical Adaptation Committee to harmonise the national work with implementation of monitoring requirements. It is of key interest that there is a harmonised monitoring procedure in Europe. Until this is the case it will be difficult or even impossible to compare monitoring results from different EU countries. The monitoring system in Sweden is uncomplicated and outlined in Table 2.1. The method will have to be adapted to reflex the EU requirement for specific information about the reuse/recycling rate in addition to the reuse/recovery rate. The recovery rate is calculated on the average value of the total number of scrapped automobiles during the year.

Table 2.1. The Swedish automobile recycling monitoring system.

Information	*Source*
A Curb Weight minus driver (70/75 kg)	National Road Administration
B Weight of body shell (to shredder)	Automobile dismantler
C Weight of landfill (%)	Shredder
Calculation	
D Reuse, energy recovery and recycling at dismantler	**A - B = D**
E Recycling at shredder	**B - C = E**
F Total recovery	**D + E = F**

The ELV directive also includes requirements on the *recoverability* and *recyclability* rate of new vehicles to be type approved. This is about how much of the new vehicle that can *potentially* be recovered, re-used or both respectively recycled, re-used or both. The requirements for these new vehicles are a recoverability rate of 95 % (of the vehicle weight) and a recyclability rate of 85 % (of the vehicle weight). At present time, it is not yet settled when this recoverability and recyclability calculation will be included in the type approval process for the vehicles, but it will be earliest in 2007.

There is an *ISO standard* (22628) that includes a calculation method for the recyclability and recoverability of road vehicles. According to the ISO standard, recyclability and recoverability rates depend on design and material properties of the new vehicles and the consideration of proven technologies. All materials and fluids that will be depolluted from the vehicle before further treatment are considered as reusable or recyclable. A component can be considered reusable or recyclable when its dismantlability is assessed and there is a proven recycling technology for the specific component and its material content. All metals are considered as recyclable. Some of the remaining non-metallic residue can be considered recyclable on the basis of proven recycling technologies and some can be considered recoverable. It is noted that technologies for energy recovery of polymers and elastomers are industrialised on a large scale worldwide. Therefore polymers, elastomers, and other modified organic materials can potentially be recovered through those technologies.

The calculation method in the ISO standard is a theoretical method that cannot reflect the process that will be applied to the vehicle at the end of its life. The lifetime of an automobile can be up to 20-30 years and it is impossible to predict the exact technologies to be used in such big advance. According to the ISO standard, every component part, material or both considered as recyclable has to be linked to a *proven recycling technology*. In this context, proven technologies means technologies that have been successfully tested at least on a laboratory scale. For the use within the type approval procedure, manufacturers have to show the type approval authorities this link between a component/material and a recycling technology. A joint European automotive project is ongoing with the intension to make a catalogue of proven recycling technologies available.

It is not always clear how reuse, recycling, energy recovery, and landfill should be distinguished between each other. For some cases the border between recycling and landfill are quite thin, e.g. when ceramic materials or ash residues are used as filling material in e.g. road construction or blocks of concrete (presently regarded as material recycling). For other cases the border between recycling and energy recovery is narrow, e.g. when organic material is used in steel production (presently regarded as recycling, because carbon in organic material is an active part of the reduction process in the blast furnace) or used in cement production (presently regarded as energy recovery). When the organic material (for example, printed circuit boards) is needed as energy resource to extract the metal it is unsure how to calculate. For different feedstock recycling methods (e.g. pyrolysis, hydrogenation, and gasification) it is unsure if this counts as recycling or energy recovery. For thermoset composite where you recycle the fibres but recover the matrix by e.g. gasification it is unsure how to define the recyclability. A clarification of these cases would help in harmonising the monitoring procedures and clarify the calculation of recyclability and recoverability. Today there are variations on how definitions are interpreted. In coming years when national recycling levels become more important this must lead to more stringent definitions. The European Commission has recently released a report, compiled by the German institute Ökopol, aimed at showing ways to overcome confusion over how the EU distinguishes between waste disposal and waste recovery operations [Sander *et al.*, 2004]. The European Commission has not taken a position yet, but it is concluded that, as waste technology has developed, it has become increasingly difficult to class an operation as only recovery or only disposal. This is because many processes will recover at least some waste whilst disposing of the rest.

Both in the monitoring procedure and in the calculation of recyclability and recoverability (according to the ISO standard) there are some simplifications made and not all *materials losses* from the recycling system are considered. All materials and fluids that are depolluted from the vehicle before further treatment are considered as recycled even though this is not necessarily always the case in reality. Furthermore it is up to the manufacturer to decide which material or components that should be dismantled and sent for recycling. One basic principle in the monitoring procedure is the fact that various materials sent to recycling or energy recovery are considered as being recovered to 100 % (except at the shredder where the remaining material is counted as landfill). This is a practical standpoint but not completely true. Not 100 % of the materials sent to recycling are in the end actually recycled, and recycling and energy processes are not efficient to 100 %. Some residues or ashes are left for landfill or similar. So, in essence, should these inefficiencies be accounted for, the monitoring procedure becomes a lot more complicated and the end recovery rate gets lower. However, the needs to consider these further details are depending of the purpose of the monitoring. To follow up on the performance of the system in separate EU member states, it should be enough to record data that demonstrate that the right course is followed leading to improved recovery.

The standards for calculating recyclability and recoverability and for monitoring should be in accordance with each other. The estimated potential re-use, recycling, and recovery should agree with the later monitored real re-use, recycling, and recovery. This would make it easier to fulfil the criteria for the real re-use, recycling, and recovery.

2.2 Recycling criteria for specific components and materials

The *ELV directive* bans the use of the four *heavy metals lead, mercury, cadmium, and hexavalent chromium* (from the 1st of July 2003). Some exceptions from this ban are stated in the Annex II to the directive, for example, lead as an alloying element in some applications, lead in batteries and vibration dampers (has to be labelled or made identifiable), and mercury in discharge lamps and instrument panel displays (has to be labelled or made identifiable). The Annex II will be revised from time to time.

The *ELV directive* also contains minimum technical requirements for pre-treatment (Annex I) concerning depollution and in order to promote recycling (from 2006). Treatment operations for *depollution* of end-of-life vehicles are:

- removal of batteries and liquified gas tanks,
- removal or neutralisation of potential explosive components (e.g. air bags),
- removal and separate collection and storage of fuel, motor oil, transmission oil, gearbox oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, air-conditioning system fluids, and any other fluid contained in the end-of-life vehicle, unless they are necessary for the re-use of the parts concerned,
- removal, as far as feasible, of all components identified as containing mercury.

Treatment operations in order to *promote recycling* are:

- removal of catalysts,
- removal of metal components containing copper, aluminium and magnesium, if these metals are not segregated in the shredding process,
- removal of *tyres* and large *plastic* components (bumpers, dashboard, fluid containers, etc), if these materials are not segregated in the shredding process in such a way that they can be effectively recycled as materials,
- removal of *glass*.

Land filling of *whole tyres* is forbidden according to the *European directive on the landfill of waste* (1999/31/EC). In Sweden, there is a regulation on *producer responsibility for tyres* (1994:1236).

In Sweden, *sorted burnable waste* is not allowed to landfill and *organic waste* is not allowed to landfill from 2005 according to the *regulation on the land filling of waste* (2001:512). This is the mayor difference between this regulation and the European directive on the land filling of waste (1999/31/EC).

The criteria in the *European directive on the incineration of waste* (2000/76/EC) may have influence on the *substance content in wasted materials for energy recovery*. The aim of this directive is to prevent or to limit as far as practicable negative effects on the environment, in particular pollution by emissions into air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste. This aim shall be met by means of stringent operational conditions and technical requirements. The directive contains limit values for heavy metals as Cd, Hg, Pb, and Cr and other substances as for example dioxins. If hazardous wastes with a content of more than 1 % of halogenated organic substances, expressed as chlorine, are co-incinerated, the temperature has to be raised to 1100 °C.

There is a *European decision on establishing component and material coding standards for vehicles* (2003/138/EC) pursuant to the ELV directive. According to the decision, producers, in concert with material and equipment manufacturers, shall use the nomenclature of ISO component and material coding standards referred to in the Annex to this decision for the labelling and identification of components and materials of vehicles, e.g. for plastics with a weight of more than

100 g and for rubbers (except tyres) and lattices with a weight of more than 200 g. Two years after the entry into force of this decision (i.e. 1 July 2005), on the basis of the practical experience gained in the recycling and recovery of end-of-life vehicles, the present decision shall be reviewed in order to establish, if necessary, component and material coding standards for other materials.

2.3 Future trends

There is a high focus on resource and waste issues today, which can be seen in documents and activities carried out by the European authorities. "Natural Resources and Waste" has been issued within the Sixth Environment Action Programme of the European Community as one of four priority areas for urgent action. Within this action programme, seven thematic strategies have been mapped out. The "waste prevention and recycling" as well as the "sustainable use of natural resources" can be seen as the most important of these strategies that concern recycling.

The thematic strategy on "waste prevention and recycling" includes options to promote recycling:

- The development of *material based recycling targets* in articulation with end-of-life products based targets;
- Getting the prices of the different waste treatment options right by using economic instruments, which could include tradable certificates, the co-ordination of national landfill taxes, promoting pay-as-you-throw schemes, and making producers responsible for recycling;
- Ensuring recycling is both easy and clean. In some cases, implementation of EU waste law may have led to unnecessary burdens on the recycling industry. Such problems need to be identified and solved. Additionally, common approaches for recycling could ensure that recycling businesses apply the best available technology.

However, the thematic strategy on "waste prevention and materials recycling" should be seen as lying underneath or as a part of the thematic strategy on "sustainable use of natural resources". At the time being, the environmental effects from using resources are seen to be larger than the resource depletion itself. The thematic strategy on "sustainable use of natural resources" strives for decoupling consumption from economic growth, which affects many parts of society and demands for large changes, so the time scale for its implementation has been set to 25 years. The main principle of this strategy is to use less/fewer resources per unit of GDP, and

- to maintain availability of resources;
- to reduce the environmental impact of development, use, and disposal of resources;
- mapping the links between use of resources and their environmental impacts to identify where action is needed.

The European research on Integrated Product Policy (IPP) may influence future requirements for recycling. IPP addresses the issue of taking the environmental aspects of the whole life cycle of a product into consideration, which includes the end-of-life phase. The IPP discussions may well lead to altered requirements for recycling, as well as a requirement for a more holistic viewpoint for producers.

The new European legislation for chemicals (REACH) may affect recycling. If the new chemicals legislation prohibits certain chemical substances as trace elements in production of new products, this may make it more difficult to find markets for recycled goods. On the other hand there is a European decision (2001/171/EC), from 2001, in which the limits for lead, cadmium, mercury, and hexavalent chromium, set in the directive on packaging and packaging waste (95/62/EC), are allowed to be exceeded in glass packaging if they are not intentionally introduced during the manufacturing process. The packaging material may only exceed the concentration limits because of the addition of recycled materials. A similar law for polymers might make the recycling of polymers easier.

An extension of the producer responsibility to encompass other products than those that are already included is not planned at the moment [Sjöberg, 2004b]. The Directorate-General Environment refers to the ongoing activities with the thematic strategy for materials recycling and prevention of waste. The European Commission thus does neither confirm nor deny that there will be an extended producer responsibility for other vehicles than automobiles in future.

Sinneka Bohlin had an assignment from Swedish Government 2001 to investigate and evaluate the existing producer responsibility 2001 [Miljödepartementet, 2001]. The assignment was to consider if legislation changes were needed and if the producer responsibility was to be extended to more product areas. The conclusions for heavy vehicles were that a big fraction is already taken care of due to a well functioning second hand market and a market for spare parts. Many of the vehicles are exported for an extended use in other countries. New regulations will come with regards to combustible waste and hazardous waste that will increase the requirements on the end-of-life treatment. Therefore the conclusion was that a legislated producer responsibility was not needed at this time.

3 The end-of-life treatment of automobiles

Every year up to 14 million motor vehicles cease to be roadworthy in the member states of the European Union and approximately 7.5 million of these are treated in Europe and the rest are exported outside the EU (according to ACEA, European Automobile Manufacturers Association). In Sweden, approximately 150,000 ELVs were scrapped per year during the years 1997 to 2000. More than 250,000 ELVs were scrapped each year in 2001 and 2002, due to a raise of the scrapping premium.

The ELV treatment can be described as a four-step-process. The four steps are *pre-treatment*, *dismantling*, *shredding*, and *shredder residue treatment*. The main driving force for improving the different operations in the ELV treatment is to increase the recycling level of metals (of economical reasons). A second effect is that recycling of other materials (such as plastics, rubber, and minerals) and use of residues as fuel will divert material from landfill and therefore reduces future landfill costs. The European End-of-Life-Vehicle Directive 2000/53/EC is also a reason for further development of the ELV treatment processes and following recovery operations.

This section gives a state of the art report about ELV treatment for the transport sector in Europe. It covers the situation today and describes development trends for the future. Processes and material output fractions of the different operations are described. Some technical, economic, and environmental aspects are also considered. More information can be found in Sjöberg [2003b], Andersson and Jonson [2004], and Liljenroth [2004] in Appendices C, D, and E.

3.1 Pre-treatment

The first step in the ELV treatment is the pre-treatment of the ELVs, when harmful substances are removed from the vehicles. This step includes for example draining of the different fluids, neutralization of pyrotechnical devices, and dismantling of the battery.

In Sweden, the following items are drained, dismantled, or neutralized today in the pre-treatment step (according to the Swedish National Environmental Protection Agency's regulations and General advice on scrap vehicle operations, NFS 2002:2):

- Oils (motor oil, transmission oil, gear box oil, hydraulic oils, brake fluid etc)
- Oil filters
- Fuel (petrol, diesel, gas)
- Other fluids (coolant/ glycol, washer fluid etc)
- Refrigerant from AC system
- Starter battery
- Components containing mercury

- Lead balance weights
- Pyrotechnical devices such as airbags and belt tensioners

In the rest of the European Union, the pre-treatment items are basically the same as in Sweden but some marginal variations can occur due to national or local regulations. Some countries, such as Greece, Spain, Ireland, and UK, have introduced the obligation to pre-treat the ELVs very recently or are in the phase of introducing this obligation.

In Sweden, some of the fluids are most often reused, e.g. fuel and washer fluid, while others are sent to special companies for energy recovery. Lead batteries and lead balance weights are recycled. The mercury is disposed of in a controlled manner.

3.2 Dismantling

The second step of the ELV treatment is the dismantling of parts. Traditionally, parts that can be re-used, either directly or after being reconditioned, are dismantled. Parts can also be dismantled and sent for material recycling. The dismantler would sort the dismantled parts into different bins containing defined fractions to be sent to recycling. The parts could either be sent whole and unbroken or they could be fragmentized in a smaller shredder at the dismantler's site to reduce the volumes and make the logistics more economically feasible. There is a variation in what fractions to be sorted and what contaminations are accepted.

Tyres are dismantled in Sweden due to the Swedish producer responsibility for tyres. Tyres are re-used, recycled, or recovered depending on their condition. *Catalytic converters* are dismantled due to a profitable recycling of precious metals such as platinum, rhodium, and palladium. *Glass* is dismantled in Sweden since 2002 and sent for recycling to reach the recovery quota set up by the Swedish Ordinance on Producer responsibility for vehicles. Dismantling of valuable *metals* is of interest when the dismantler gets paid more money for the sorted metals than the money he/she spends on dismantling. Today, metals are dismantled only in exceptional cases, as the infrastructure for recycling metals after shredding is established and economically feasible since years. *Polymeric* parts has been dismantled and recycled in a number of different studies but there is no commercial recycling of polymers from ELVs today because of an uneconomic situation.

In the very beginning of the discussions about how to increase the recovery and recycling quotas from the ELVs, the main focus was on extending the dismantling of parts. The advantages of the dismantling route are low investments and that you receive rather big parts containing identified, and to a limited number of, materials. The big disadvantage is that manual dismantling is costly. There have been many studies performed on this topic. In the ECRIS project, dismantling times for a number of parts and vehicles were recorded [Anonymous, 1998]. Also some theoretical studies on the economics of dismantling and recycling have been carried out [Spicer et al, 1997; European Information Network, 2000]. It is concluded that some technical problems exist regarding the quality of sorting and separation and that the labour cost for dismantling components is high. It is also concluded that recycling of non-metals via traditional dismantling procedures (i.e. disassembly) will not be economically feasible despite attempts at Design for Recycling or changes in the marketplace.

In a study from Ernst & Young, operating costs and income for dismantling have been obtained from 25 dismantlers in France [Gazzo, Pétapermal, and Schmeitzky, 2003]. The analysis shows that the average operating cost, including transport costs on purchases, purchase of ELVs, staff costs, general expenses, and depreciation and provisions, is 546 Euro/ELV, which is lower than the average operating income, including sale of goods and services, of 517.4 Euro/ELV.

There are reasons for shredder companies to encourage dismantlers to perform a *shredder oriented dismantling*. The reasons are to increase the quality and the value of the metallic output of the shredder, reducing hazardous materials in the residues, and reducing the total amount of residues going to landfill [Nijerk, 1998]. Shredder-oriented dismantling would comprise:

- removal of copper- and chlorine-containing parts to ensure a specific quality for materials recycling and energy recovery.
- draining of the fluids and/or removal of fluid-containing components to make shredder light fraction more resistant to leaching. (NB: Today, this is usually done at the pre-treatment of ELVs.)
- stripping the automobiles of large polymer components to reduce the quantity of shredder light fraction.

Copper-containing components are dismantled only in a few cases, although the copper content is one of the main sources for deterioration of steel quality in material recycling. EU DG XII supported work has started to imaging solutions for recovering larger quantities of copper from electrical motors via the "crushable core electrical motor" design for recycling route. No change of the present situation towards a shredder-oriented dismantling can be expected, for example, as long as the fees for landfill are as low as present.

3.3 Shredding

The third step of the ELV treatment is shredding. Shredders originated in the late 1950s to deal with the increasing number of ELVs arising, as the old practice of hand dismantling could not keep up with even the relatively low volumes of ELVs in those days. Shredders have been steadily developed to increase efficiency, enhance the purity of the product (i.e. the materials fractions out), and especially to achieve optimum separation of the metals contained in a vehicle.

The ELVs are shredded in a hammer mill followed by sorting and separation of different material fractions, which are sent for recycling directly or for further separation before the material is recycled. There are three main materials outflows from the shredder: *ferrous metals*, *non-ferrous metals*, and *shredder residues*. A shredder plant often treats different sources of scrap such as ELVs, white goods (refrigerators and cookers etc.), brown goods (TV and other entertainment products), and municipal waste metallic scrap. It is not very common that ELVs are treated separately, which after metal separation leaves an *automotive shredder residue* (ASR). Instead, the different sources of scrap are mixed in certain proportions to attain a desired metal content to be sorted out and the other materials end up in the shredder residues (SR).

At the shredding plant the ELVs are cut into fist-size pieces and fed onto a conveyor belt into the shredder, see Figure 3.1. The *light residues fraction (fluff)* is separated from the rest by using air currents. Typical figures for the content of ASR light fraction are presented in Table 3.1.

Table 3.1. Typical figures for the content of ASR light fraction [Francois, 2003].

Material	Composition and particle size	Content (wt%)
Polymers	2-10 cm	9
Foams PUR	10/10-20/20 in cm (size of PUR pieces in the residues)	8
Rubber	Long pieces (gaskets seals), no tires	3
Metals	Wires / Al plates	2.5
Cu wires	Length: 10-20 cm	1
Wood	Pieces 10-20 cm	1
Mixed PUR with textiles	Textiles, carpets, leather etc	32.5
Minerals	Stones, sand, glass, dust etc	43

A magnetic separation is used to remove the magnetic *ferrous fraction* from the other materials. In this way, the main fraction of a shredder installation is obtained. In order to meet the requirements of the steel industry, one or more hand-pickers watch over the quality of the ferrous scrap. Some unwanted materials are sorted out of the scrap by hand, i.e., mostly ferrous parts that are polluted with unwanted material, for example, starter rotor (i.e. Cu), electrical wires and tire pieces (i.e. rubber). The separated shredded ferrous scrap obtained has a ferrous content of 98 % (range from 95-98 %) and a copper content of 0.20-0.25 % (down to 0.01 % feasible) [BIR, 2004]. This material is used to direct feeding into a steel-making furnace. In the EU alone, shredders produce over 8 million tonnes of this furnace feed material annually – around a third of total world output.

The remaining fraction, after the magnetic separation, is called the *non-ferrous (NF) mix* and consists mainly of non-ferrous metals (Al, Mg, Cu, brass, Cu-Zn, stainless steel, Pb etc) and heavy residues. At some shredder plants an *Eddy Current unit* is installed, using an alternating magnetic field to remove the *heavy residues fractions*. The proportion between the heavy and the light residues fraction is approximately 1:3 by weight. SR composition will vary depending upon type of shredding operation considered and on the input of materials. Typical figures for the content of ASR heavy fraction are presented in Table 3.2.

Table 3.2. Typical figures for the content of ASR heavy fraction [Francois, 2003].

Material	Composition and particle size	Content (wt%)
Polymers		19
Rubber	Tires (45 %), seals and gaskets (55 %)	55
Metals	Fragmentised Fe and non ferrous metals	5
Wood		7
Textiles	Small pieces	3
Cu wires	Cable (5-15 cm)	3
Minerals	Stones, up to 100–500 g/piece	8

The last step is a *heavy media separation* (*sink floating line* in Figure 3.1) for the separation of *non-ferrous metals*. Media separation plants can either be located in connection to a shredder or separately, and not all shredders are equipped with such a unit. Media separation plants employ fluids or mineral suspensions of varying specific gravity that allow selected materials to float while the others sink. Thus a succession of different media separation stages within a single plant can effectively separate materials one from another. Media separation plants currently recover around 99.5 % of the non-ferrous metals from shredded vehicles. The purification of the metal fractions are in average in Europe between 98-99 % for the fractions of *stainless steel alloys*, *aluminium alloys*, and *copper alloys* [BIR, 2004]. These fractions are sent for recycling. There is also a mixed fraction (*fine mixed metals*) that contains different alloys of copper-zinc, copper-tin, and zinc [BIR, 2004]. This fraction is often sent to countries with lower labour costs, for example China, for manual sorting and recycling.

The EU's shredder and media separation infrastructure is economically self-supporting. The "EU average" shredder operating cost can be estimated to 20-25 Euro/tonne [Liljenroth, 2004]. Operating cost includes here investment, labour, energy, material, and maintenance. Another analysis of operating costs and income for shredders give an average operating cost of 89.9 Euro/incoming tonne, including transport prior to arrival, purchase of materials, wages and salaries, disposal of shredder residues, general costs, and depreciation and provisions [Gazzo, Pétapermal, and Schmeitzky, 2003]. In the same study, the average operating income for sales of materials is estimated to 92.5 Euro/incoming tonne.

The revenue of a shredding operation will depend upon the purchased price of the automobile wreck and of other feed, specific operation, labour costs, cost of disposal, and value of the ultimate ferrous and non ferrous fractions, which are very much fluctuating as any commodity does. The amount of material passing through the installed shredding capacity in EU has been reduced and the economic conditions distorted due to an increased export of ELVs to Eastern Europe. The ELVs are exported to countries where treatment cost is lower and dismantling schemes are financially supported by national or local authorities. The consequence of more polymers in automobiles and consequently more SR is another increasing pressure on the economic margins of the shredder operation.

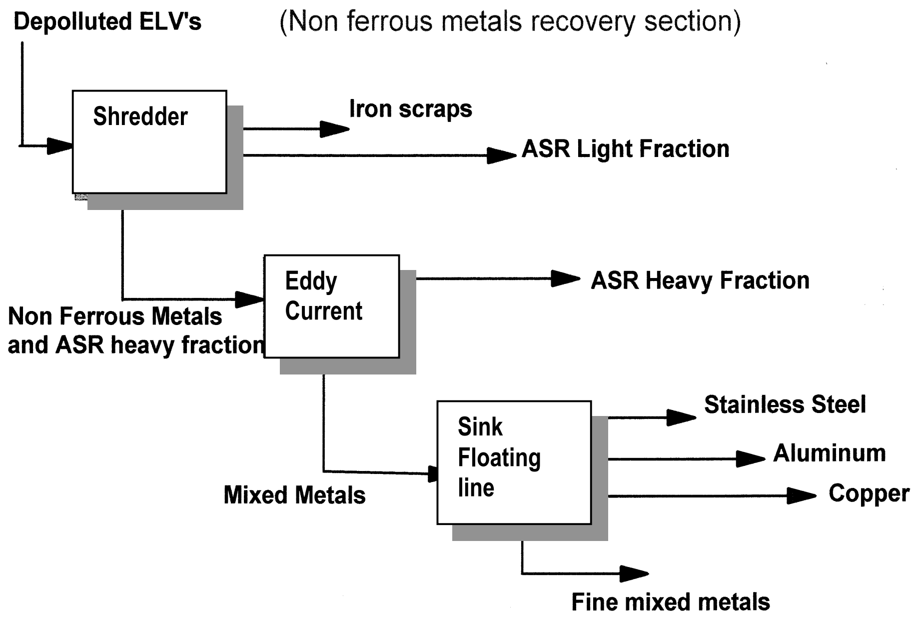


Figure 3.1. Layout of a shredder process [Plastics in ELV, 2002].

3.4 Shredder residue treatment

The last and fourth step of the ELV treatment is the shredder residue (SR) treatment. The shredder residues remaining after the metals are sorted out can be treated further, either to recyclable or recoverable fractions.

An average ELV today weighs approximately 1000 kg, of which approximately 75 % is recovered as metal. Hence the remaining materials become SR (25 %). The shredder residue production in Europe has been estimated to 2,500,000 tonnes of which the light fraction is the main part, i.e. 2,000,000 tonnes [European Commission, 1999]. These residues have up to now been put on landfill, representing approximately 0.2 % of total landfill waste in the EU [BIR, 2004].

The share of shredder residues may increase in the future at the same rate as the share of polymeric materials is increasing in the automobiles. The polymer parts of an ELV are forming up to 15 % of the total ELV at present, and this rate will increase even more in the near future. To be able to cope with the increasing amount of polymeric material in automobiles and requirements of environmentally friendly disposal and sustainability, conversion in the shredding process of mainly polymers into a potentially valuable fraction will be required.

Increasing efforts are put into research how to further sort shredder residues. These efforts have several goals. Main driver is to increase the metal recycling level of the shredder operation and following steps. In additions, sorting of the SR fraction will facilitate plastic recycling and recycling of other fractions as minerals and rubber. Last but not least, fractions can be tailored for use as fuel in combustion processes. As a consequence the amount of residues going to land fill will also decrease [Bontoux and Leone, 1997; Large and Zariatti, 1999]. There are a number of technologies for treating the SR, and several reports are available, for example, [European Information Network, 1999; ACEA, 2002]. Research and development continues in this area and technologies for SR treatment are described in this section.

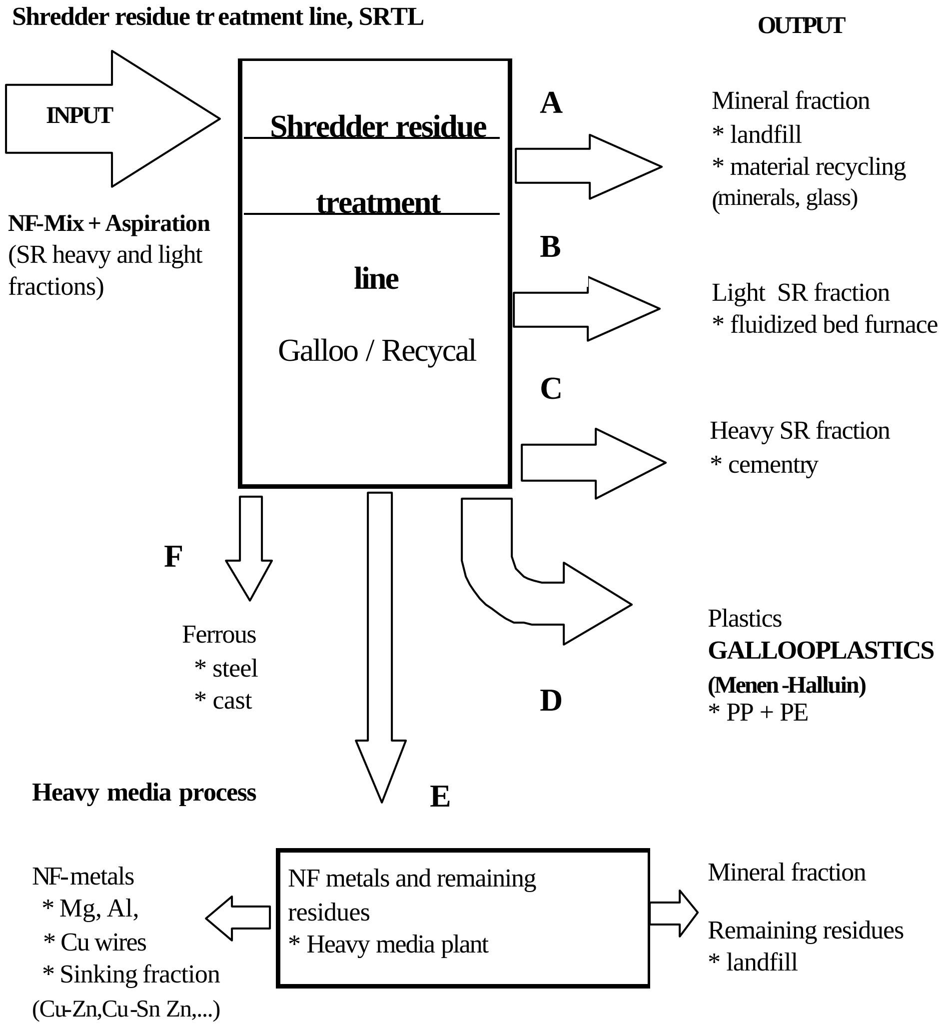


Figure 3.2. General layout of the Galloo shredder residue treatment line [Francois, 2003; APME/EUCAR, 2003].

3.4.1 Separation of metals

Metals can be further separated from the shredder residues by magnetic and eddy current separation and by a heavy media step. For example, shredding plus post-shredding processes recover 98 % of the metal content (ferrous and non-ferrous) of the automobiles in The Galloo Shredder Residue Treatment Line (SRTL) [Francois, 2003; APME/EUCAR, 2003], see Figure 3.2.

3.4.2 Separation of polymers for material recycling

The American Plastics Council has worked with MBA Polymers Inc., Recovery Plastics International and Argonne National Laboratories in investigating froth flotation [Anonymous, 1999]. In early plastic-plastic separation pilot plant studies by the American Plastics Council (APC) in 1994-95, it is demonstrated that different plastics (PE, PP, ABS etc.) collected from ELVs by selective manual dismantling often had overlapping densities. The reason for this is the use of various additives including pigments, fillers, and reinforcements. Using "skin" or "froth" flotation technologies give a possibility to separate these materials despite overlapping densities. Both technologies are based on chemical surface properties of respective materials. In both the "skin" and "froth" flotation technologies, surface cleaning is applied prior to flotation. "Froth" flotation is using an air stream blown through water affecting material surfaces differently. Air bubbles are attached to the surface pending surface properties (regarding float/sink). "Skin" flotation is using a wetting agent also affecting material surfaces differently (regarding float/sink). However, these technologies need to be more developed: laboratory scale measurements of surface chemistry are needed to adjust the process, and larger scale evaluation to separate rubber from plastics is needed. The *Recovery Plastics International* (RPI) separates plastics with froth flotation [ACEA, 2002]. The process can handle nearly all types of shredder residues.

Preliminary work has demonstrated that a combination of density separation methods with "skin" or "froth" flotation separation methods would enhance the recovery of engineering plastics from shredder residue [Liljenroth, 2004]. Large-scale demonstration defining potential to separate main plastic families like ABS, PC, PP, and PU has shown promising results. Preliminary economic calculations have been assessed for a 10,000-tonnes/month plant. Information about the shredder composition was collected from a special study, which investigated different types of SR: conventional mixed streams as well as only automotive. Treatment costs of SR have been roughly calculated to 50 Euro/tonne at large throughputs.

In the *Galloo Shredder Residue Treatment Line* (SRTL), there is one plastic fraction that contains PP and PE. The plastic fraction constitutes 10 % of the material output, and today the main reason for running the SRTL process is recycling of plastics. In the SRTL, the shredder residues are subdivided, by mechanical separation of heterogeneous fractions, into five main fractions (of which the plastic fraction is one) plus an additional iron collection [Francois, 2003; APME/EUCAR, 2003]. The two main functions of the SRTL are to increase the metals collection from the residues and to prepare new fractions of products for both material recycling, energy recovery, and feedstock recovery processes.

Today polyolefins (PP+PE) are recovered from the plastic fraction by Galloo Plastics in separate fractions. They are transformed by extrusion into ready to use compounded granulates, which are sold to plastic moulding industry. Galloo-Plastics processes recycle 50 % of the total PP and PE amount in the vehicles. Most of the Galloo-Plastics products are used in the automobile industry. For example recycled granulate is used in the manufacturing of "shock absorbers" in the bumpers of the new Renault Megane. In addition, a continuous production of polystyrenes granulates from the SRTL started in 2002. Further improvements by the SRTL are being made to recover all the thermoplastics such as ABS, PA, PC, etc.

The Galloo group operates three SRTL since 1995. Two plants are located in Belgium and one in France. The Galloo Recycling group includes recycling companies for ferrous and non-ferrous metals in Western Europe. The running cost for the SRTL as described above, including investment, is estimated at around 25 Euro/tonne (year 2000). The cost includes investment, labour, energy, material, and maintenance. This cost does not include further treatment steps at Gallo-Metal, Galloo-Plastics etc.

Salyp has concluded a licensing agreement with the Argonne National Laboratory (University of Chicago - Department of Energy) concerning a technology for the recycling of the plastic fraction present in automobile shredder residue (ASR) [Salyp, 2003]. With this technology – at laboratory scale – ASR is initially separated into three different streams, two of which contain plastics. One of these streams is the contaminated polyurethane foam coming from e.g. automobile seats. In a subsequent process this foam is cleaned to a potentially reusable quality. A second stream contains hard plastics and elastomers. Salyp intends to offer a mechanical recycling technology to extract and recycle these plastics. The final output from the Salyp process are:

- Purified plastic pellets (separate fractions of PE, PP, ABS, PC etc): ready for re-use in high-end applications;
- PU foam flakes: ready for re-use;
- PU foam powder: ready for re-use into high-end applications in a mixture of 15 % recycled and 85 % virgin product.

The two basic steps of the Salyp mechanical process are separation and pelletisation (production of pellets) of the sorted softened chip in a stamping press. The separation mode operates on differential softening and adhesion behaviour of those plastics contained in ASR when subjected to heat (infrared heating device) and pressed through rolls. All thermoplastics demonstrate a physical change when heated. The intensity of the change depends upon temperature and polymer types. The plastics are not heated above their typical melting point but to a point just below it: the softening temperature. The specific properties of softened plastics (surface adhesion/surface softness) are then used for a mechanical separation. The process yields dry plastics pellets that carry no thermal degradation. The focus of current developments is to examine the range of the shredding system with changing parameters and an input of various kinds of plastics. The surface contamination effects, the process selectivity, the product quality, the range of properties obtained and the ability of the process to be up-scaled remain to be tackled. Salyp's aim is to extract up to 70 % of the value potential in ASR.

In *iron and steel production* a reducing agent is needed since there may be unwanted iron oxides in the iron ore. This is traditionally done with coke, coal, or heavy oil, but tests with mixed plastic packaging waste have been successful

[Sjöberg, 2003b]. This technology is accepted as material recycling. Shredder residues, which have been treated mechanically, are blown into the blast furnace. The residues are then converted to hydrogen and carbon monoxide, which react with iron oxide to form metallic iron, carbon dioxide, and water. Analyses of pig iron and slag show that they are of same composition as before (no unwanted hazardous substances). The waste gas from the blast pre-heater contains carbon monoxide, carbon dioxide, nitrogen oxide, sulphur dioxide, hydrogen fluoride, hydrogen chloride, and hydrogen bromide. Hydrogen chloride content was somewhat higher than before, probably due to input of PVC. No increase of the emissions of dust particles, heavy metals, polychlorinated dioxins or furans in the waste gas has been detected. One prerequisite for usage of SR in this way is that it is properly separated (mechanically) before being fed into the blast furnace. Inert material such as metals should be removed so that the organic material content is increased. At Stahlwerke Bremen, mixed plastic packaging has been used as a reducing agent since 1994. Trials with SR have been conducted in co-operation with Daimler Chrysler and Bregau Institute.

Organic material in the SR can be material recycled or energy recovered by a *chemical conversion technology that involves gasification.* This technology is used at SVZ Schwarze Pumpe in Germany in a process where shredder residues and other types of wastes are gasified and converted into methanol to be used as a fuel [ACEA, 2002]. The gasification takes place in a moving bed gasifier. Organic matter is partially oxidized to CO and H_2 (the synthesis gas for production of methanol). Non-combustible materials are collected and put to landfill. Another site where gasification is used is in the Montello process in Italy [Sjöberg, 2003b]. SR and iron scraps from the shredder process are fed together into the rotary kiln. The iron scraps mixes the SR, which keeps the SR from overheating in some areas and from sticking to the walls of the kiln. The organic material is gasified and the gas diverted to a post-combustion chamber. The iron is heated, melted and cleaned by the high temperature and used for steel rods and bars for concrete reinforcement. Flue gas from the post combustion chamber is cleaned. Any excess gas from the kiln is used for steam generation or energy recovery.

3.4.3 Separation of minerals

The *minerals* in SR, i.e. glass, gravel, and sand, can be separated and used as a filling material in the road construction industry. For example, one of the material fractions out from the Galloo Shredder Residue Treatment Line (SRTL) is a mineral fraction that is approximately 40 % of the material output [Francois, 2003; APME/EUCAR, 2003]. Currently, this fraction seldom find any usage, normally it is land filled. Research is being carried out to investigate the upgrading of this fraction for the road construction industry, i.e., a less amount of organic materials and metals (especially heavy metals). There is also research to separate glass from the other minerals in a following process, and to recycle the glass for packaging or fibres. The recovery of the mineral fraction is an important issue for the further improvements of the SRTL process.

3.4.4 Separation of fuel fraction for energy recovery

Before shredder residues (SR) are used for energy recovery, it can be an advantage to *remove chlorine-containing materials*. There are two main problems with chlorine content in SR for energy recovery. Firstly, chlorine contributes to formation of corrosive gases in the incineration system. Secondly, chlorine may, under certain incineration conditions, form dioxins. The main chlorine-containing material in automobiles is PVC.

In 1997, Renault started a state of the art study on existing processes and facilities to extract chlorinated materials from SR [Sciberras, 1999]. The objective was to find new techniques able to achieve the separation of these products to obtain substitute fuels from SR with lower chlorine content. An evaluation of existing techniques showed that it was not possible to use or optimise density separation in order to meet chlorine requirements for SR used in energy recovery. Electrostatic sorting was one potential way but the humidity level in the SR need to be controlled at a constant level. However, identification of chlorine through radioactive florescence (RXF) was found as a feasible method. Renault set up a consortium of partners that had interest in the development of an automatic separation process for chlorinated materials in SR. According to the results obtained during the first step of the project the Consortium felt confidence to be able to develop a pilot in France. The overall objective is to industrialize the process and sorting equipment for use at recycling and/or shredder facilities. There are also other development projects in which the chlorine-containing materials are extracted from the SR (and put on landfill), for example, at the Belgian Scrap Terminal (Craenhals) at Willebroek [Liljenroth, 2004] and in the Galloo Shredder Residue Treatment Line [Francois, 2003; APME/EUCAR, 2003].

Stena Gotthard Fragmentering and Volvo Car Corporation in Sweden carried out a project during 1998 through 2001 called Shredder Waste Recycling [Anonymous, 2001], partly financed by the EU LIFE Environment programme. The aim of the project was to convert shredder waste into a quality assured energy fraction and increase recycling of iron and metals while minimizing the residues to be land filled. The project shows that the best way to effectively quality assure shredder residues is to de-pollute the waste to be shredded before it arrives at the shredder plants. Without de-pollution of scrap, the shredders in Sweden will receive about 300 kg of mercury and 5 tonnes of PCB yearly, mixed in the scrap to be shredded.

There are two material fractions out from the *Galloo Shredder Residue Treatment Line* that can be used for energy recovery [Francois, 2003; APME/EUCAR, 2003]. The "light fraction" (30 % of the material output) consists mainly of foam and textiles. It comes mainly from the light shredder fluff. This fraction can either be used for energy recovery or material recycling. Currently Galloo is working with a supplier to automotive industry to prepare sound insulation materials for vehicles using foam extracted from this fraction. The "heavy combustible fraction" (15 % of the material output) contains mainly rubber, polymers, and wood. The calorific value of the mixture is 26 MJ/kg. The cement industry in Belgium and Northern France was particularly interested in the 1990's in this fraction of reliable quality to be used as a solid fuel substitute. From 1995 to 2000, 15,000 tonnes/year have been recovered in the Belgian cement kiln of C.B.R. at Antoing as a *refused derived fuel* substituted to solid coal fuel. Today the volume is close to 4,000 tonnes/year, due to the competition of other refused derived fuel, including plastic waste from other sources.

There are also other SR treatment processes that produce *fuel products for the cement industry* [Sjöberg, 2003b]. The SR often has a content of metals that is too high and it has to be refined before usage. The use of SR in cement industry has one advantage over others in that there is no sludge to be put to landfill after the process. Inorganic matter becomes part of the cement. One problem is that the content of copper often is high, even when refinement of SR has been carried out. Also chlorine contents in SR have to be decreased. Some different techniques have been tested for refinement: dry separation (Comet Sambre, Belgium), wet separation by flotation (Chapparal Steel, USA), thermolysis (THIDE, France), or molten slag gasification at high temperature (ScanArc Technology, Austria). The methods that have given the best results are wet separation and molten slag gasification. VALERCO was founded by CFF and VICAT in 1991, and has its own SR treatment. The VALERCO line is made of a riddle, shredder, two over bands and an eddy current separator. The output is mixed with shredded tires and industrial waste before usage in cement industry.

One of the resulting material fractions from the process developed by Mutabor GmbH in Germany is a fuel product, which is used at Scandinavian *cement industry* (Scancem) as a fuel in their cement kiln [Anonymous, 1997]. Plastic packaging waste is added in the process to increase energy content and to decrease the potential problematic with high metal content in the fuel. Inorganic materials are not removed thus becoming a part of the final cement product. Investment cost for the 10-tonnes/hour plant at Ueckermonde is approximately 5 million Euros. Small-scale test has been successful while large-scale trials are pending. Expected gate-fee, charged by the operator for treatment, will be around 95 Euro/tonne SR.

Co-combustion with Municipal Solid Waste (MSW) for energy recovery is a method that has been used in full scale in several countries for some years, mainly in Germany, France, and Switzerland [Sjöberg, 2003b]. Light and heavy fraction SR can be mixed into the MSW with up to 20-30 % of fuel weight. An increase in metal contents in flue gas, fly ash, and residues can be seen. In the flue gas there is an increase in the content of arsenic, lead, and zinc, which is reduced in the flue gas cleaning. In the boiler ash and residues there is an increase of zinc, copper, antimony, cobalt, nickel, and lead. The co-combustion technology has the advantage in that it can be done without further modifications of the MSW combustion plant. This gives it an economical advantage compared to other alternatives. The gate fee ranges from 30 to 250 Euro/tonne.

There are also *other technologies for energy recovery*. These methods differ from traditional incineration or chemical conversion in that they have only been used in pilot scale and are not as well known and tested as the other technologies for energy recovery [Sjöberg, 2003b]. Examples of these technologies are incineration in rotating furnace and fluidised bed or treatment with municipal solid waste in the "Von Roll – RCP" process, where the MSW and SR undergoes pyrolysis, melting, sludge treatment, and post-incineration. The Schwel/Brenn-process in Germany is another example of technology that has been tested. The process is of a two-stage type that starts with pyrolysis in a rotary kiln. The pyrolysis gas and residual coke are combusted in the second step. Minerals in the coke are molten and discharged via water bath for granulation. Flue gas is cleaned in multistage system.

3.4.5 Costs for SR treatment processes

Some estimated costs for SR treatment processes are included in connection to the processes described earlier in this section. There are high uncertainties in these estimations, which are reflected in the wide variation of the costs.

According to Holderbank (Swiss shredder company), the total investment cost for a wet process SR treatment unit of 50,000 tonnes/year, is in the range of 5 million Euros [Degré, 1998]. The operating cost is 50 Euro/tonne. Operating cost includes investment, labour, energy, material, and maintenance. For a dry process the investment would be 3 million Euros.

APME (Association of Plastics Manufacturers in Europe) and VKE (German Association of Plastics Producers) commissioned the engineering company Fichtner, in 1998, to make a study to compare and validate processes in Europe for mechanical SR treatment [Fichtner Engineering Company, 1998]. The focus was on dry processes, because these processes are believed to be able to run economically with smaller capacity. Within these dry processes, the high-tech processes give products of better quality at higher recovery rate. Investment and treatment costs are however higher compared to low-tech processes. A treatment plant with a capacity of 30,000 tonnes/year (three shift operation), based on the information describing the most relevant technologies, would result in operating cost of 120-130 Euro/tonne SR (operating cost includes investment, labour, energy, material, and maintenance).

One of the lowest costs for a SR treatment process is presented by the Galloo group, which operates three Shredder Residue Treatment Lines in Belgium and France since 1995 [Francois, 2003; APME/EUCAR, 2003]. The largest plants have a capacity of 100,000 tonnes/year. The running cost for these plants is estimated at around 25 Euro/tonne (year 2000). The cost includes investment, labour, energy, material, and maintenance. This cost does not include further treatment steps at Gallo-Metal, Galloo-Plastics etc.

There are also variations in the estimated costs for using fractions of SR as a fuel. Cost for SR co-combustion in Sweden was estimated in the ECRIS project to 22-32 Euro/tonne SR in 1998 [Liljenroth, 1999]. The SR underwent treatment before co-combustion. ECRIS (Ecological car recycling in Scandinavia) was a recycling project run in Sweden between 1994-98, initiated by Volvo Cars and engaging several actors in the ELV recycling chain. SR-pyrolysis using Siemens technology shows promising, and costs are estimated to be approximately 150 Euro/tonne for a commercial plant for MSWI (municipal waste incineration mixed with SR) with a capacity of 150,000 tonnes/year [Christill, 1998]. According to the information of BIR, there are possibilities to treat residual shredder light fraction through pyrolysis in Northrhine-Westfalia, Germany, at a cost estimated to 250-500 Euro/tonne (planned by RAG).

3.5 Landfill

Shredder residues, especially ASR, are normally disposed to landfills all over Europe. There are regional differences in the costs as well as in the environmental standards of the landfills. Depending of the location of the landfill in each country there are also large cost differences. Presently in Europe the costs are in the range 20-170 Euro/tonne [Henton, 1998; Mark, 1998].

The cost for landfill is usually low compared to costs for further treatment of the SR, for example, to separate the "cleaner" and more calorific fractions to be turned into an alternative fuel. The cost for landfill is generally lower than for ASR/MSW combustion [Henton, 1998; Mark, 1998]. In countries where the MSW combustion is wide spread it is still an option that can be utilized without large investments. On the other hand the political pressure against shredder residue incineration in some countries is high.

4 The end-of-life treatment of trucks and rail vehicles

More information can be found in Wendin [2003] and Larsson [2004] in Appendices F and G.

4.1 Trucks

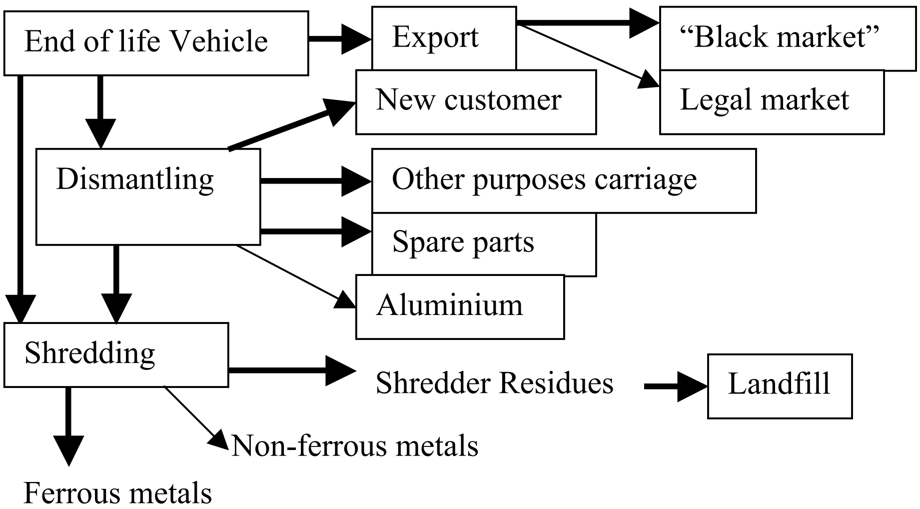


Figure 4.1. End of life scenario for trucks.

In Sweden, approximately 13 % of new registered trucks (37,000 vehicles) are being registered off road each year [Barsoum, 2003]. Off these trucks 48 % go to export, 26 % are taken care off by an authorised dismantler, 15 % are dismantled or used by other means, 3 % are not in traffic, and 8 % are reregistered to other vehicles or have not been noticed for two years, see Figure 4.1. It is assumed that a limited fraction goes directly to shredding, whereas a fraction of ca 1600 trucks is assumed to be exported annually for the black market purposes. During the past 30 years, the share of trucks going to export has been continuously increasing with and peak in the late 80's and in beginning of 90's [Hultberg, 2002].

In Sweden, there are approximately seven major dismantlers, which together have a throughput of approximately 1200 vehicles per year. Many of the vehicles passing through the dismantler are possible to sell directly further to a new customer (approximately 30 % or 360 vehicles per year). The dismantler keeps the truck as storage of spare parts as long as possible. Demanded spare parts are dismantled as well as precious materials such as aluminium. In addition, the chasses are sometimes sold as a carriage. When the truck is no longer worth keeping, it is sent to shredding at Stena Gotthard Fragmentering AB (four facilities), where it is cut to smaller pieces and sent to material recycling at Stena Gotthard Återvinning AB (54 facilities).

In Europe, in general, there is no registration when trucks are taken off road. Therefore it is not possible to know much about their end of life.

According to the prior project manager for Recycling at Auto Recycling Netherlands (ARN), there is no statistical information regarding the end of life of trucks in Netherlands. The most probable alternative is the export [von Celdhuizen, 2003]. According to Jansen [2003] (the successor of von Celdhuizen), there is not much done for recycling on ELV trucks in the Netherlands. Some truck dealerships do have their own dismantling halls, but they only dismantle trucks that have been in accidents. They dismantle spare parts for the spare parts market. The remaining materials progress to a shredder site (steel), and to the normal waste disposal routes (waste materials). Before the truck will be shredded it is drained off oil and other fluids. However, this treatment represents only a few percent of the total of ELV trucks [Jansen, 2003]. Similarly, STIBA has a special group of truck dismantlers [Laar Franklin van de, 2003]. STIBA is the Dutch association of certified car, motorcycle, truck and related dismantlers.

Export to Africa is probably the most common end of life for trucks in France [Otdjian, 2003]. There are two categories of economic actors: dismantlers, which disassembly manually the automobiles and sell components, and crushers, which destroy the cars and sort the different materials by automatic ways. Renault is responsible (at the economic level) for the end of life treatment of the vehicle put on the market, and chooses between dismantlers and crushers. A main actor of recycling that Renault is in contact with is a company called CFF Recycling (http://www.cff.fr). CFF Recycling runs local community waste collection centres. In addition, approximately fifty metal collection centres have been set up as receptions for all small quantities of metal waste. In France, the dismantlers are certified according to an established system. A large dismantler in France is Valerco located in Lyon (dismantle only automobiles).

4.2 Rail vehicles

In Sweden and rest of Europe there is no official registration when rail vehicles are taken out of service. The owners are often big companies and the market has gone from state owned business towards private operators and actors the last couple of years. In many cases the timing of the determined scrapping/taking out of service is dependant on when a new *vehicle fleet* is being bought in. The life length of the existing fleet has most often been extended with appropriate maintenance, overhaul and refurbishment during the lifetime. Especially the interior and the textiles need refurbishment after a couple of years. Component re-use is high since the vehicles often are kept as storage of spare parts a couple of years. In some cases the vehicles are refurbished and sold to other operators after they have been taking out of service. There are some examples of rail vehicles left in nature, but in absolute most cases legislation, control and the high metal content imply pre-treatment and recycling activities of the end-of-life vehicles. The end-of-life activities are similar in European countries.

SJ in Sweden will during 2002-2005 scrap 158 passenger cars from the 60's. The 40-tonne-cars from SJ are sent to O Hallquist Återvinning AB in Nykroppa, Värmland. Electrical and electronic equipment and environmental hazardous components are being removed e.g. the rectifier equipment that may contain PCB. Fluids, glass, porcelain, PVC-carpets, wood, plastics, and insulation are being removed. Other scrap is being cut down to smaller pieces and the metal content is being extracted and recycled [Nilsson, 2004].

About 600 old metro cars have been scrapped by SL, Sweden, between 1998 and 2003. The scrapping was made in same pace as modernization was made by SL and new metro cars, manufactured by Bombardier Transportation, was bought in. The 25-tonne-cars were, after pre-treatment at Tågia, sent on truck to Stena Bilfragmentering AB in Gladökvarn, Huddinge, Sweden. The entire cars were cut to pieces (after that too thick pieces were disassembled and manually reduced in size) and shredded.

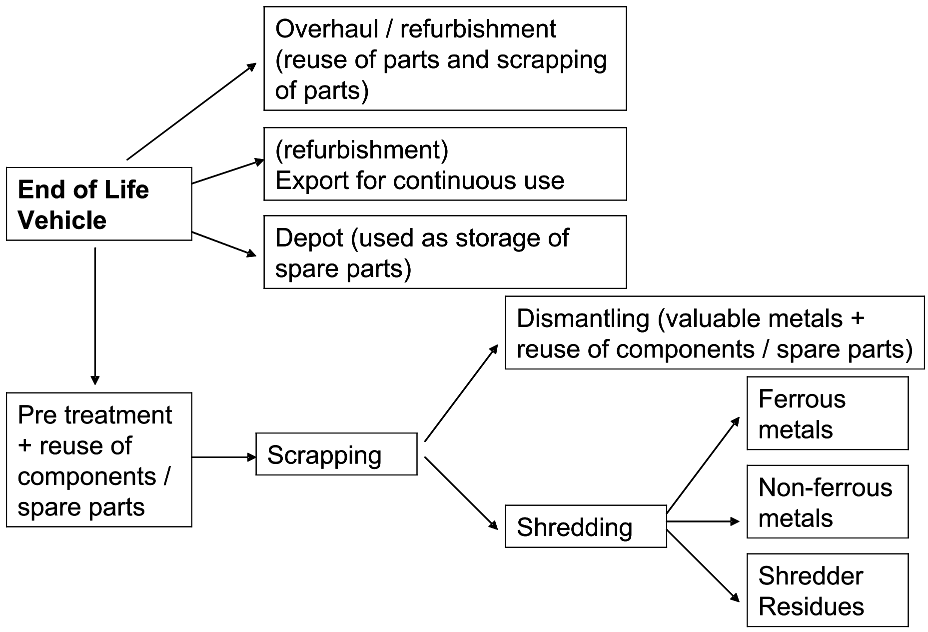


Figure 4.2. End of life scenario for rail vehicles.

Differences between end-of-life treatment of automobiles and rail vehicles are:

- *Control:* The operators/owners know exactly where the rail vehicles are. The business is state-owned or run by big private operators the end-of-life treatment is controlled by laws. Private consumers are not involved and there is little risk that a rail vehicle is simply left in nature.
- *Number of end-of-life vehicles:* Due to the larger number of automobiles scrapped per year, the waste volumes of rail vehicles are smaller than the volumes of automobiles. According to the ELV directive (2000/53/EC) between 8 and 9 million tonnes of waste are related to EoL automobiles. No corresponding figure has been found for rail vehicles, but it is considerable smaller.
- *Simplicity:* The larger series of automobiles and the producer responsibility facilitate an optimization of the EoL treatment for automobiles.

- *Life length:* In practice, automobiles have less than half the service life compared to rail vehicles. DfR strategies must therefore be more long-termed chosen for rail vehicles.
- *Size/weight:* Automobiles are much smaller and are therefore easier and less expensive to scrap.
- *Material:* The parts that need to be disassembled prior to shredding do not look the same and they differ in size and location. General material content has similarities but is not exactly the same.
- *Legal producer responsibility:* The automotive industry has a legislated producer responsibility in EC; the ELV directive is restricting both what is built into the automobiles and recycling rates are also specified in the directive

Similarities with end-of-life treatment of automobiles are that:

- *Pre-treatment:* Removal of components containing similar hazardous components is needed (e.g. batteries, fluids and components containing heavy metals).
- *Waste legislation:* Same waste legislation at national and EC level must be followed (e.g. European Waste Catalogue (EWC) and 91/689/EEC on hazardous waste).
- *Shredding plant:* Same shredding plants and technique is normally used after that the rail vehicles is cut down to smaller pieces. This means that the same recovery processes for different material fractions are possible.
- *Requirements:* Customer requirements in the rail industry are similar to the legislated requirements within the automotive industry, e.g. producer responsibility per project and targeted recycling rates.

Rail manufacturers are generally open for a contract-to-contract based producer responsibility. Since rail vehicles have a considerable longer life length and often are rebuilt during life length, the importance of specifying the responsibility in contract writing is very big. The time aspect and the condition/completeness need to be specified as well as the responsibility back to sub-suppliers and if e.g. interior refurbishment and change of ownership occurs. The manufacturer can normally assist with recycling descriptions and material contents of the rail vehicle as originally built. The manufacturer also facilitates recycling by a modular design to facilitate an easy maintenance, disassembly, and refurbishment.

5 Recycling of materials and the material market

The materials in a vehicle can be divided, roughly, into the material categories metals (70-80 % of the weight), polymers (10-20 %), glass (< 5 %), and others (< 5 %). Today, the main part of the metals is recycled. Furthermore, tires are recovered in some countries. Glass is recycled at least in Sweden and thermoplastics are rarely recovered.

The type and amount of materials that are recycled depend on available recycling technologies, cost of recycling processes, resulting material qualities, and demand of recycled materials.

In this section, different recycling options for a selection of materials are described, and material qualities and some potential applications of recycled materials are discussed.

5.1 Aluminium

Some of the valuable properties of aluminium are: light weight, good electrical and conductivity, good strength, and the ability to screen off electro magnetic fields. The aluminium is also corrosion-resistant; forming a surface oxide layer when exposed to air that prevents further corrosion. Another advantage is that it is very easy to recycle without loss of quality.

Aluminium is used in diverse sectors such as electrical engineering, automobiles, construction, plumbing, machinery, shipbuilding, aircraft, and precision instruments. Within the automotive industry, aluminium is used for e.g.

- engine
- axles
- airbag containers
- brackets
- rim
- chassi parts
- body
- front hood, tale gate, doors
- interior parts (e.g. carrier system for I-beam, chair supporting structure

The average use of aluminium per car is on an upward long-term trend. According to EAA (European Aluminium Association), the forecast growth should reach 130 kg per car by 2005 and by year 2015 the average use of aluminium per car is expected to increase to about 200 kg. As an example, a Volvo V70 contains today about 140 kg of aluminium.

5.1.1 Recycling system and processes

Aluminium products can be produced from primary aluminium, based on the mineral bauxite, or from remelt aluminium from process scrap and used aluminium products, see Figure 5.1. Aluminium, as a material, circles in a closed recycling loop. The casted aluminium can only be recycled into casted aluminium. This is illustrated in Figure 5.1 by a separate closed loop for casted aluminium.

Pure aluminium is very soft and its range of application is therefore limited. By alloying the aluminium with other metals, the properties of the aluminium can be altered to a great extent. The main alloying ingredients are iron, silicon, zinc, copper and magnesium.

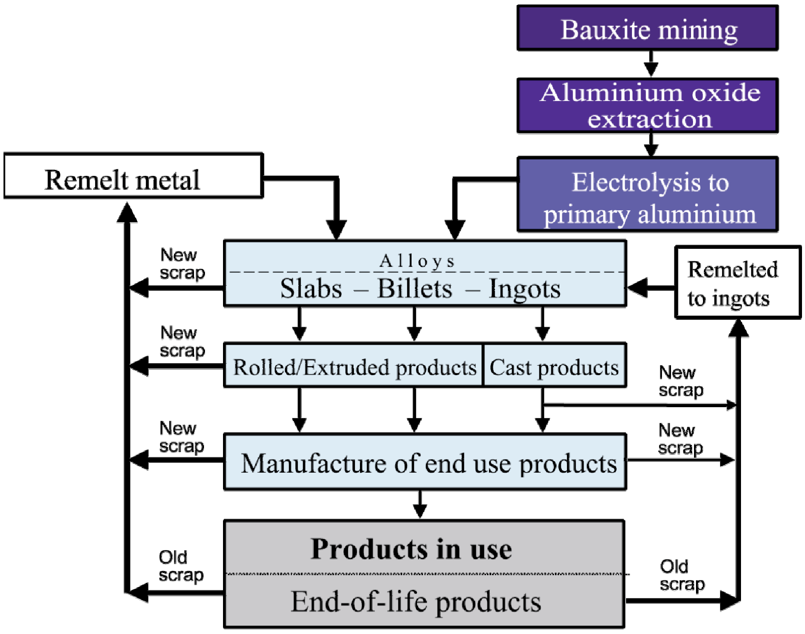


Figure 5.1. A schematic illustration of primary and remelted (secondary) aluminium production.

One of the inherent qualities of aluminium is the fact that this metal in general can be recycled after its use without loss of quality. Aluminium has been recycled since the production of the metal started on a commercial scale in the early days of the 20:th century.

Today, all modern aluminium mills and foundries recycle the substantial fraction of metal that is internal scrap to their process. The alloy of this process scrap is usually known and this scrap is often clean (not mixed with other materials). However, some types are lacquered or greasy and therefore need to be treated before remelting. Secondary aluminium is produced from a variety of scrap materials ranging from beverage cans to end of life vehicles and aircraft.

In many cases the mixed scrap that is going to be recycled has to be sorted according to type and size by means of different technologies, such as magnetic and eddy current sorting, flotation, screening etc. Depending on the quality and the amount of impurities in form of other materials, e.g. lacquers, paints, oil etc., the scrap is then de-coated. This can be done by passing the scrap through an oven or a mesh conveyer whilst hot gases are circulated through the mesh to volatilise or burn off the coating.

A large part of the scrap is converted into foundry ingot, which is used to produce high-quality aluminium castings. An increasing share of the scrap is remelted into slabs for rolling or billets for extrusion. Some scrap is used for production of de-oxidiser for the steel industry or hardeners and master alloys for further use within the aluminium industry.

The production of aluminium from recycled metal uses down to 5 % of the energy of primary production (electricity and thermal energy). Melting of aluminium would not be difficult if it not were for the high tendency of aluminium to oxidise. This means that the metal exchange when remelting the aluminium is not 100 %, since there are losses related to the oxidisation. Estimated metal exchanges when aluminium is remelted are presented in Table 5.1.

Table 5.1. Estimated metal exchange when remelting aluminium. Estimations based on knowledge within the aluminium industry [Strömberg, 2000].

Aluminium scrap	**Metal Exchange** [weight %]
General/default	85
Clean and undyed[1]	95
Casted:	
Old scrap/used product	90
Process scrap	94
Chips, shavings (briquetted)	87

1) A clean and undyed product represents a product that is free from oil and other materials such as e.g. plastic, paint, and steel screws.

Due to the mixture of different aluminium alloys and presence of impurities, the aluminium fraction from a shredder is normally used for producing casted aluminium.

Effects of impurities

A disadvantage of iron (Fe), copper (Cu), and some other impurity or alloying elements in aluminium is e.g. that, if present at sufficient concentrations to form a second phase in the structure, their presence results in the formation of weak spots in the oxide film that gives aluminium its corrosion resistance. The corrosion resistance can be greatly reduced as a consequence, since integrity of protective oxide films is important to the overall corrosion resistance of aluminium.

A high presence of zinc and magnesium makes the aluminium harder causing crack formation. Since the magnesium has a lower fusing point than aluminium it is "heated off" by simply turning the heat on the furnace up. Therefore, the presence of magnesium is not such a big problem. Zinc, on the other hand, can only be diluted since it is impossible to remove.

Lead makes it easier to turn the aluminium, but the tolerance level for lead is quite low. The strength of the aluminium is highly affected by to high concentrations of lead.

The most common problem for remelters is stainless steel. The stainless steel usually enters the flow of collected aluminium by accident. Usually it has been put in the same fraction as aluminium, since someone could not tell the difference between the two. The alloying elements nickel and chromium make the aluminium too hard and rigid causing crack formation. Nickel and chromium can only be diluted since they are impossible to remove.

5.1.2 Material market and flows of recycled material

For many years the biggest end-use market for aluminium has been the transportation sector. More than a quarter of all aluminium is used in the transport sector. Originally indispensable for its lightweight for the aerospace industry, aluminium is now widely used in cars, buses, coaches, lorries, trains, ships, ferries, aircraft and bicycles.

Significant sources of scrap arise in the former Eastern Block and in the past this source has been responsible for significant falls in market prices. The main market for aluminium alloys produced by the secondary aluminium industry is in transport, mainly for vehicle castings (engines, cylinder heads and gearbox casings). Developments in the transport industry to produce lighter and more economic vehicles means that there is growth for aluminium alloy in this sector. In Europe, the average use of aluminium car components is estimated to increase from a level of 85 kg per automobile in 1998 to 180 kg per automobile in 2010. The estimated increase is mainly due to the use of more body parts in aluminium, but also due to the high recyclability of the material.

The aluminium industry is the youngest and largest of the non-ferrous metal industries. Scrap aluminium has significant value and commands good market prices. This fact indicates that there is a well-established commodity market for aluminium and that there are no distinct bottlenecks for increased material recycling. According to EAA, European Aluminium Association, the world production of primary aluminium is today about 27 million tonne, see Figure 5.2.

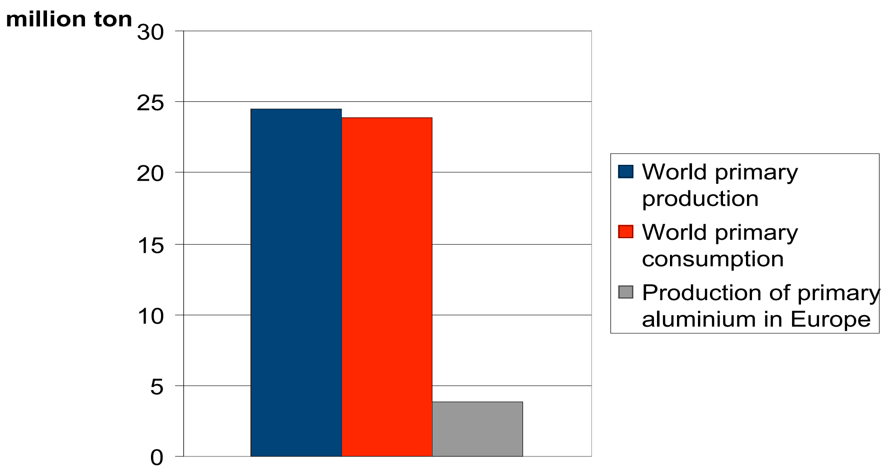


Figure 5.2. World primary production and consumption of aluminium in 2001, and the production of primary aluminium in Europe in 2000. Source: EAA.

5.1.3 Recycling classes

The recycling classes in Table 5.2 are based on how Stena Aluminium in Sweden classifies aluminium scrap. The recycling classes are based on the chemical content of the material. The content intervals reflect the 60 aluminium specifications for scrap Stena Aluminium uses. The specifications are adjusted to reflect the Swedish standard for aluminium alloys. The aluminium content in each class is rarely lower than 90-weight %, since all maximum tolerance levels are not exceeded at the same time. [Strömberg, 2000]

Table 5.2. The allowed chemical compositions of alloys for the different recycling classes (R-classes) for aluminium [Strömberg, 2000]

R-class	Weight percent	Si	Fe	Cu	Mn	Mg	Ni	Zn	Sn	Pb	Ti
Non alloyed	max	0.50	0.50	0.05	0.10	0.05	0.05	0.10	0.05	0.05	0.05
	min	0	0	0	0	0	0	0	0	0	0
Low alloyed	max	1.3	0.40	0.10	1.0	0.80	0.05	0.10	0.05	0.05	0.05
	min	0.30	0.40	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
High alloyed	max	1.3	1.0	6.0	1.5	5.0	0.30	5.0	0.20	1.2	0.20
	min	0.35	0.40	0.10	0.50	0.30	0.01	0.20	0.01	0.01	0.05
Casted Al	max	13.5	1.2	5.0	0.50	1.0	0.30	2.0	0.20	0.30	0.20
	min	0.25	0.25	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Non-alloyed aluminium

Un alloyed aluminium is relatively limp due to lack of alloying elements. Within this fraction you usually find thin aluminium sheets that are quite new, license plates, road signs, and aluminium wire.

This class is the purest class and it has therefore no limitations to the area of use and it can in many cases replace primary aluminium.

Figure 5.3. Compressed unalloyed aluminium ready to be remelted [Strömberg, 2000].

Low alloyed aluminium

With a higher content of alloys, as e.g. silicon and magnesium, the low-alloyed aluminium becomes more rigid compared to non-alloyed aluminium. Extruded profiles, cooling coil, and flat-rolled aluminium are examples of low-alloyed aluminium products.

High-alloyed aluminium
The class for high-alloyed aluminium has a high tolerance for e.g. silicon, copper, magnesium, zinc, and lead, see Table 5.2. Bumper, load-bearing beam, checkered plate, and automobile body parts are examples of products produced with high-alloyed aluminium.

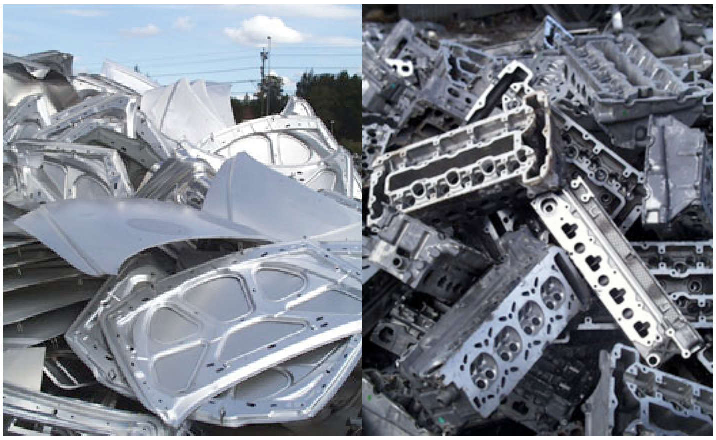


Figure 5.4. Uncoated aluminium bonnets and engine blocks ready to be remelted [Strömberg, 2000].

Casted aluminium
Casted aluminium has a high content of silicon, copper, and zinc. Aluminium rim, gearbox, and engine block are examples of casted aluminium products.

In order to cast aluminium, a high content of silicon is needed. When producing casted aluminium, it is therefore very valuable to the producer to use other casted aluminium products. The producer can then avoid adding so much virgin silicon.

5.1.4 Recycling value

The recycling value represents the quotients between the scrap material price and the virgin material price on the commodity market for metals in London (London Metal Exchange). For aluminium, as for other materials that are circulating in well-established markets for recycled materials, these quotients are fairly stable. The recycling values presented in Table 5.3 were developed in Strömberg [2000]. The values were developed together with Gotthard Aluminium AB and Sapa Recycling and Technology.

Next to the recycling class for chips, the class with high-alloyed aluminium is the largest within the aluminium recycling industry. In order to give incentive to recycling, this class was given two different recycling values. When the high-alloyed aluminium is sorted by type of alloy the economical value of the material is increased. This is due to the fact that the recycler then can make use of the chemical composition of the material to a greater and more efficient extent since the composition is defined and well known. In addition, the cost for sorting the material at the recycler decreases.

Both high alloyed and casted aluminium is used when producing new casted aluminium. As mentioned above, the high silicon content in the casted aluminium is very valuable to the producer. The recycling class for casted aluminium has therefore a higher value than the unsorted high-alloyed aluminium. When the recycling class isn't known, a value of 0.75 has been estimated e.g. for non/low/high alloyed aluminium used for producing casted aluminium.

Table 5.3. Recycling values for aluminium and different recycling classes. A clean and undyed product represents a product that is free from oil and other material such as e.g. plastic, paint, and steel screws [Strömberg, 2000].

Recycling class	Recycling value
Non alloyed aluminium	
- clean and undyed	0.88
- general	0.88
Low alloyed aluminium	
- clean and undyed	0.80
- general	0.80
High alloyed aluminium (unsorted)	
- clean and undyed	0.70
- general	0.70
High alloyed aluminium (sorted by type of alloy)	
- clean and undyed	0.80
- general	0.80
Casted aluminium	
- old/used product	0.75
- new process scrap	0.75
- originally non/low/ high alloyed Al classified as casted Al due to its chemical composition	0.75
Chips - bricletes	0.50

5.2 Copper

Copper has been used for many centuries. Copper and the copper alloys has a very high thermal and electrical conductivity, is highly corrosion resistant, and has a high workability, weldability and solderability.

Copper is used in diverse sectors such as electrical engineering, automobiles, construction, plumbing, machinery, shipbuilding, aircraft, and precision instruments. Within the automotive industry, copper and its alloys are used for e.g.

- radiators
- connectors
- cables
- gear wheels
- nozzles
- altenator
- bearings
- components for the breaking system
- starting engine
- printed circuit cards and electronics
- mechanical components (e.g. in automatic transmissions and ABS braking systems).

The increase use of electronics in automobiles has lead to a more than threefold increase in the average amount of copper per vehicle. A Volvo V70 contains today about 20 kg copper.

5.2.1 Recycling system and processes

Refined copper is produced from primary and secondary raw materials. The output of the copper refineries is copper cathode, see Figure 5.5. This is remelted, alloyed and further processed to produce rods, profiles, wires, sheets, strips, tubes, etc.

The copper scrap can also be remelted, alloyed, and processed further. Depending on the alloy content and the condition of the scrap, it can be remelted and used for the same purpose again, used in a copper product that e.g. needs to be alloyed further, or remelted to be used within the brass industry. If the copper scrap is very complex, e.g. as printed circuit cards, the copper scrap is re-smelted and refined into copper cathodes. All copper scrap that is re-smelted and refined into copper cathodes gains the same purity and properties as primary copper.

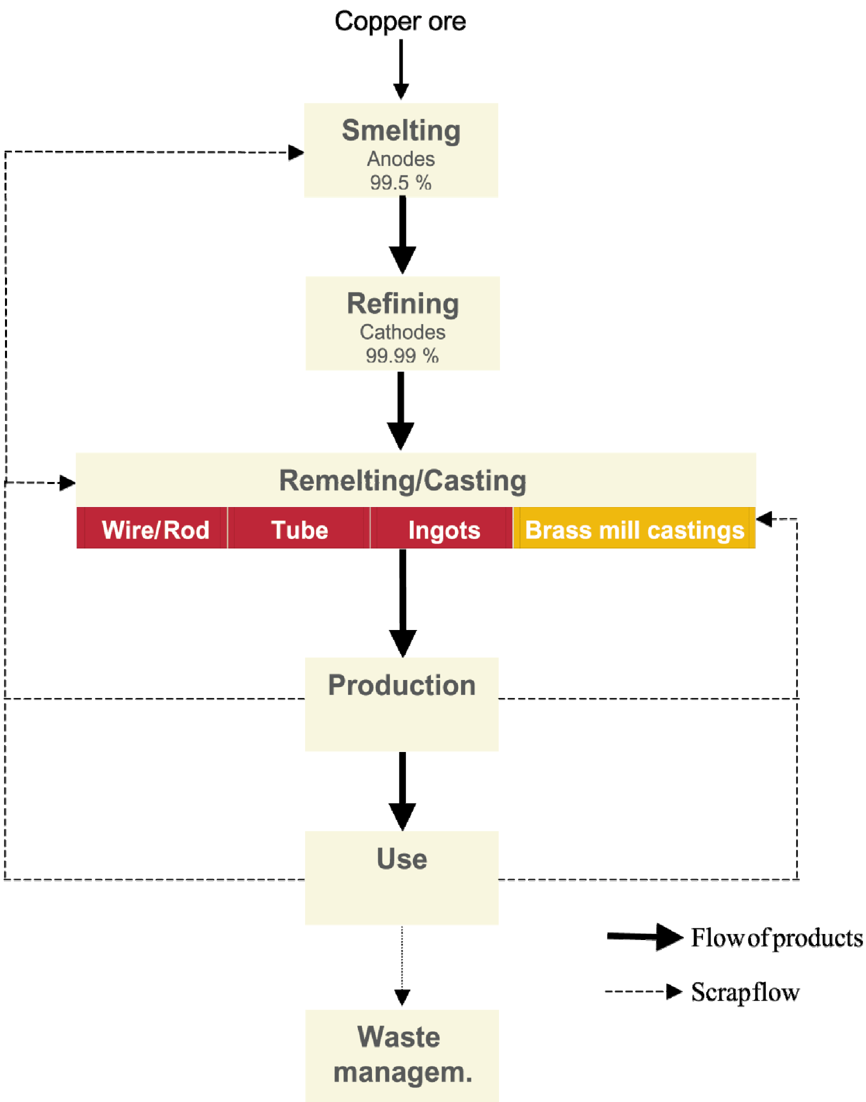


Figure 5.5. A simplified schematic description of the copper flow.

The reclamation of copper from residues and wastes relies on two principal stages of processing. These are:

- smelting including roasting and sintering, to produce metal of a suitable quality for subsequent treatment
- refining

Scrap preparation
All scrap used must be prepared and analysed prior to processing to alter its shape and size and/or its purity. This can some times add significant cost to its use. Scrap preparation may be done by manual, mechanical, pyrometallurgical or hydrometallurgical methods.

Manual separation and cutting of large pieces of scrapped items is very necessary, as is an accurate analysis of the material. Large, solid items are reduced in size by diamond saws, shearing machines, pneumatic cutters, or manually by a sledgehammer.

Mechanical methods include sorting, stripping, shredding, and magnetic and air separation. Because scrap is a bulky material, the customary practice is to bale light scrap and cut heavy scrap to size so that it can be handled. The scrap may be further compressed by hydraulic press into briquettes, bales, bundles or hockey pucks. Brittle, springy turnings are crushed in hammer mills or ball mills to reduce bulk for easier handling. Slags, drosses, skimmings, foundry ashes, spills and sweepings may be ground to liberate prills or other metallics from the non-metallics so that metallic fraction can be recovered by gravity separation or other physical means.

Smelting
Smelting is usually carried out in three stages of processing in sequence to produce metallic copper in a form that is suitable for electrolytic refining to further improve its purity. These are:

1. using a blast furnace to improve the copper content of the waste from about 30 % to 80 %,
2. a converter (both conventional and top-blown rotary) and/or reverberatory furnace to improve the copper concentration from 80 % to about 95 %
3. followed by an anode furnace to give a product for electrolytic refining containing ~99 % copper.

The fume and dust produced in the furnaces is collected on filters and usually is either returned to the blast furnace or provides a feedstock for the recycling of other metals such as zinc and tin.

Refining
Refined copper is produced from primary and secondary raw materials. The output of the copper refineries is copper cathode. This is melted, alloyed and further processed to produce rods, profiles, wires, sheets, strips, tubes, etc. This step may be integrated with the refinery but is frequently carried out at another site.

The refineries, as e.g. Boliden Mineral AB at Rönnskär in Sweden, produce high quality copper out of concentrated ore, copper scrap, and ashes from the remelting industry.

Usually, refining is carried out using an electrolytic process in which the cast anodes from the smelting process are placed in an electrolytic cell with a cathode and sulphuric acid as the electrolyte. The copper is transferred and deposited on the cathode in the process thus producing high purity copper. Cathodes are either sold as such for others to process or melted in a furnace and casted into physical forms such as billets, slabs, rod, etc. for sale. Impurities collect in the bottom of the electrolytic cell as slime. This is removed from the cell from time to time and processed, or sold on to others to process and extract other metals.

Effects of impurities

During casting, rolling, wire drawing, and annealing operations impurities can cause:

- Severe cracks,
- Rod surface defects and internal defects,
- Reduction in the working life on the mill rolls,
- Notable decrease in die-life in wire drawing,
- Decrease in drawability, especially in fine wire drawing,
- Adverse effect on annealability of the metal
- Effect the electrical conductivity

Bismuth	Has a very low solubility in copper and crystallises along the grain boundaries, causing embrittlement.
Selenium	Forms Cu_2Se at the grain boundaries causing embrittlement. The effect of selenium is decreased by the presence of oxygen by forming Se_2O instead (which does not cause embrittlement).
Tellurium	Causes an effect similar to selenium.
Lead	Has a low solubility in copper and crystallises along the grain boundaries, causing embrittlement. Makes it easier to turn the copper.
Antimony	Can form compounds with copper, e.g. Cu_3Sb, which has a low melting point. Antimony also has a significant effect on the electrical conductivity.
Iron	Is the most common impurity. Iron in high concentration has a significant effect on the electrical and thermal conductivity.
Nickel and chromium	Are used as surface treatments. Lowers the electrical conductivity

Environmental issues

Using recycled copper instead of producing new copper saves a lot of energy. The energy intensity for recycling of copper varies by the purity of the scrap. Clean scrap, which requires only remelting, requires only about 1 MWh/tonne. Scrap that requires electrolytic refining requires about 6 MWh/tonne and that which must be purified by re-smelting requires about 14 MWh/tonne. [Copper Development Association, 2001]

5.2.2 Material market and flows of recycled material

Copper is one of our most common metals; only iron and aluminium are used in a greater extent. Copper scrap is a highly prized raw material, especially in Asian and European nations with scarce natural raw material sources for copper. As a result, export controls on scrap have been commonly applied in many nations in the world. As an example, Russia has put a duty of 17 % on copper scrap exported from Russia. Representing about 40 % of the world's copper consumption, Asia used about 8.3 million tonnes of copper in 2002, see Figure 5.6. Usage in Europe totalled about 5.6 million tonnes.

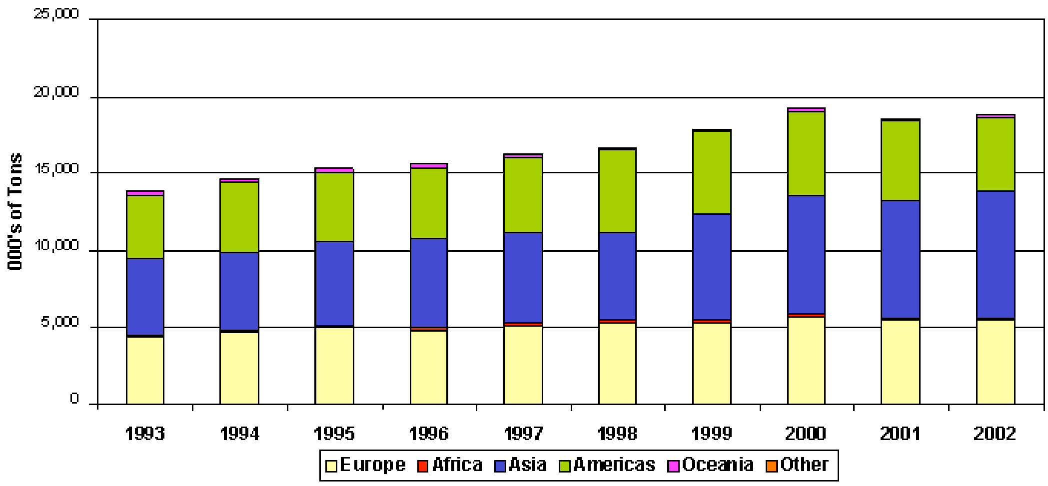


Figure 5.6. Global copper supply. Source: World Bureau of Metal Statistics.

Demand for copper mainly comes from the electrical and electronics industries, which absorb almost 60 % of total EU usage. These industries use copper primarily as a conductor material to carry electricity. This copper needs to be as pure as possible so that the conductivity is preserved. The purer the copper is, the easier it is to draw a copper wire. The construction sector is the second largest user. Excluding building wire, it accounts for approximately 25 % of the total copper demand. A wide variety of semi-finished products, of both alloyed and unalloyed copper, are used in plumbing, roofing, decorative fittings etc. The remaining demand cover industrial machinery and equipment, transportation equipment and user products. [European Copper Institute, 2004]

Remelting of copper into different products

Pure copper is used in a copper wire. This wire is produced from copper cathode, see Figure 5.5, which can be made from virgin copper or from re-smelted and refined copper scrap. The copper wire can be remelted into e.g. copper pipes, see Figure 5.7. The copper pipes can be remelted into copper pipes again or remelted into a copper radiator, depending on the alloy content of the pipe. The radiators contain more alloyed copper and are therefore not suited to be remelted into e.g. pipes. This kind of high alloyed copper is common to be remelted within the brass industry. [Henriksson, 2003]

How the flows of copper scrap are treated (remelting or re-smelted and refined) is driven by economic factors. Re-smelting and refining of the copper is very expensive compared to remelting. Therefore, mostly very complex (e.g. printed circuit cards) or very high alloyed products is re-smelted and refined into copper cathodes, since this kind of copper scrap is not that expensive to purchase compared to copper with lower alloy content. It is most likely that the treatment of copper scrap will continue to be recycled in the same way as it is today.

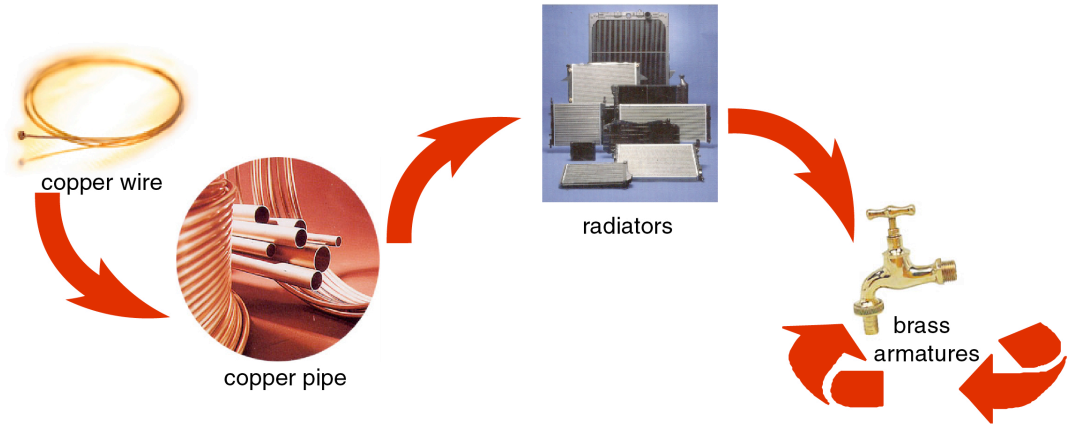


Figure 5.7. A schematic illustration of an example of how the copper can be remelted into different products.

5.2.3 Recycling classes

The recycling classes in Table 5.4 have been developed together with Outokumpu Copper [Eriksson, 2003] and Boliden Mineral [Henriksson, 2003]. The recycling classes are based on the chemical content of the material.

Table 5.4. The allowed chemical compositions of alloys for the different recycling classes for copper material.

Recycling class	Cu wt%		Al	As	Be	Bi	Fe	Mn	Ni	P	Pb	Sb	Si	Sn	Zn
Unalloyed copper	99.9	max	-	-	-	0.0005	-	-	-	0.001	0.005	-	-	-	-
		min	-	-	-	-	-	-	-	-					
Copper alloys	92-99.9	max	0.2	0.005		0.0005	0.50	-	0.2	0.06	1.5	-	-	0.5	1.50
		min	-	-	-	-	-	-	-	-					
Unalloyed brass	63-75	max	-	-	-	0.0005	-	-	-	0.001	0.01	-	-	-	37
		min	-	-	-	-	-	-	-	-	-	-	-	-	5
Alloyed brass	55-75	max	4	0.25	-	-	2.5	4	3.5	0.35	3.7	0.1	0.8	4	rest
		min	-	-	-	-	-	-	-	-	-	-	-	-	rest
Tin bronzes	79-94	max	0.005	-	-	0.0005	0.25	-	2.0	1.2	0.5	0.2	0.005	20	5.0
		min	-	-	-	-	-	-	-	0.05	-	-	-	4.0	-
Brass bronzes	67-94	max	0.01	-	-	-	0.7	0.05	6.0	1.5	34	0.8	0.2	17	17
		min	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper nickels	53-98	max	2.0	-	0.7	-	2.30	5.5	46	0.05	0.05	0.02	1.2	8.5	1.0
		min	-	-	-	-	0.05	-	1.0	-	-	-	-	-	-
Nickel silvers	42-74	max	0.01	-	-	-	0.45	6.4	26	0.25	2.5	-	0.25	0.6	45.2
		min	-	-	-	-	-	-	2	-	-	-	-	-	6.15

5.2.4 Recycling value

The recycling value represents the quotients between the scrap material price and the virgin material price on the commodity market for metals in London (London

Metal Exchange). The values in Table 5.5 were estimated by CIT Ekologik together with Boliden Mineral (Strömberg and Henriksson).

There is a large uncertainty when it comes to valuating the brasses, bronzes, copper nickels, and nickel silvers. When the copper content is lower than about 90 %, the costs for refining it increases rapidly and the price you would get for the material on the commodity market decreases. The cost is however not as high if the material is only to be remelted. Some assumptions have been made as an attempt to overcome these difficulties. One shall notice that the copper market has been unstable the last couple of years, which naturally makes it even harder to present recycling values.

In order to estimate the recycling values for brasses, bronzes, copper nickels, and nickel silvers, only the economic value of the copper content and the content of the most valuable alloys have been considered[1]. When more accurate values are needed, we recommend a recalculation of the recycling values based on the present market situation.

Table 5.5. Recycling values for copper material and different recycling classes.

Recycling Class	Recycling Value
Unalloyed copper	0.95
Copper alloys	0.85
Unalloyed brass	0.70
Alloyed brass	0.60
Tin bronzes	1.20
Brass bronzes	0.65
Copper nickles	1.40
Nickel silvers	0.55

As can be seen in Table 5.5, the class for tin bronzes and copper nickels has a higher value than the virgin copper price. This is due to the presence of the valuable alloys tin and nickel. The price on the commodity market for tin is today about three times higher than virgin copper, and the price for nickel is more than four times higher.

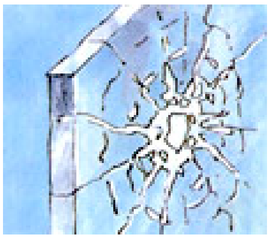
5.3 Glass

Glass is made by melting together several minerals at very high temperatures. Silica, in the form of sand, is the main mineral and is combined with soda ash and

[1] Recycling value = value of the most valuable alloys * market factor / economic value of virgin copper. The market factor may change over time. Here the market factor has been set to 0.90 based on how scrap from stainless steel is valuated.

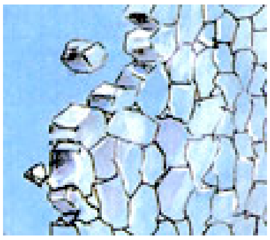
lime. Other chemicals[2] are also added to produce different colours or properties. The properties of the glass depend on the glass composition and the rate it is allowed to cool. Glass is ideal for a wide range of uses from packaging and construction to fibre optics.

Within the automotive industry, glass is most commonly used for the windscreen and the side and rear windows. The glass may contain electrical wires made of silver or other metals for antennas or defrosting systems. Two main types of glass are used:



Laminated glass for the windscreen

A laminated glass consists of a sandwiched construction with two or several glass "glued" together with use of a plastic membrane, usually PVB (Polyvinylbutyral). If the glass would break, the membrane keeps the glass together and the risk for passenger injuries are minimised.



Toughened glass for side and rear windows

The glass can be strengthen about five times, compared to ordinary flat glass, by cooling the glass rapidly after having heated it up. By toughening the glass, especially the rapture pattern is affected. If the glass is exposed to strong force, the glass will be shattered into small unsharp pieces that minimises the risk for the passengers to get seriously cuts.

5.3.1 Recycling system and processes

When it comes to recycling issues, glass can be divided into three different categories: flat glass[3], automotive glass and container glass. The flat glass and automotive glass cannot be recycled into new flat glass because of quality issues. This is due to that the quality requirements are much higher for flat glass than for container glass. Chemical composition is critical for float glass production[4] and the composition of the cullet must exactly match the glass composition in the furnace. To ensure these standards are met, flat glass manufacturers will often only recycle material that originates from their own processing plants. Flat and automotive glass contain e.g.:

- Silicon dioxide 69-74 %
- Sodium oxide 12-16 %

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[2] Additives may be magnesium oxide, aluminium oxide, zinc oxide, lead oxide, arsenic trioxide, antimony trioxide, sodium nitrate, or potassium nitrate. Colouring additives are oxides of copper, iron, nickel, manganese, chromium, or cobalt.

[3] Flat glass is used in architectural applications. Sometimes also automotive glass is referred to as a type of flat glass. In the context of recycling issues, however, flat glass from architectural applications differ from automotive glass.

[4] In the float process, when flat glass is produced, molten glass, at approximately 1000ºC, is poured continuously from a furnace onto a shallow bath of molten tin. It floats on the tin, spreads out and forms a level surface.

- Calcium oxide 5-12 %
- Magnesium oxide 0-6 %
- Aluminium oxide 0-3 %
- Minor materials (traces of allowed additives for tints)

Glass for bottles and jars have a different chemical composition and is therefore not recycled together with flat or automotive glass. Mixtures of glass with different chemical contents can cause defects when remelting, which makes such mixtures unsuitable for the very high quality flat glass required by the automotive industry.

After removal from the vehicle the glass is processed to produce cullet. In the cullet processing plant the ELV glass is crushed and subjected to a series of refining processes i.e. magnetic separation to remove metals, air jets to blow out lighter elements such as the plastic interlayer etc.

Dismantling
The glass must be removed from the vehicle and sorted by type according to the proposed end use i.e. laminated, silver printed rear windows etc. The removal of the glass is complicated by the fact that in modern automobiles the fixed glazing is bonded to the body. The cost for the removal is about 4-5 Euro per automobile [GEPVP, 2004]. It is important that any contamination is kept to a minimum if the quality is to be high.

Laminated glass
The sandwich construction of the laminated glass limits the recyclability dramatically. Flat glass itself is challenging to recycle because of its different chemical composition from container glass. Flat glass and automotive glass can be successfully recycled into construction aggregate or other secondary markets if the glass can be separated from the film. Separating film plastic from windshield glass requires the glass to be broken adequately to free the film, while keeping the film in large enough pieces that it can be removed without fouling the equipment.

Laminated glass stripper
The laminated glass is collected in whole pieces and transported in specially adapted cages. At the plant, the glass is crushed and the laminate is separated from the glass. The laminate is incinerated with energy recovery, whereas the glass is sent to a glass wool producer.

In Sweden this technology is used by e.g. Scandinavian Glass Recycling AB. Scandinavian Glass Recycling AB recycled 118,000 laminated windshields from Sweden and 22,300 from Norway in 2002. They also accept other types of toughened or laminated glass.

Effects of impurities
The float glass manufacturing process is extremely sensitive to very low levels of contamination. The following two tables highlight the main problem areas and the risk to float glass quality if not controlled.

Table 5.6. Main problem areas associated with cullet usage [GEPVP, 2004].

Potential problem areas	Quality risk if not controlled
Cullets from glass are of different compositions (different chemical makeup) e.g. automotive glass from several manufacturers, bottle glass and glass from tableware or ovenware.	Ream in the glass which appears as distortion. Note: Ream is simply a region of glass within the product, which has a composition different from the average.
Clear and tinted glass i.e. iron level	Glass colour and solar control properties
Contamination issues (metal attachments, adhesives, glass printing, heating and antenna wires, plastic from laminated glass)	Inclusions, bubbles, ream knots, colour variation

Table 5.7. Examples of the effect of contamination [GEPVP, 2004].

Type of contamination	Effect
Aluminium	Silicon inclusions and major bubble outbreak
Silicon Carbide	Major bubble outbreak
Carbon	Affects melting and foaming causing inclusions and bubble. Also colour is affected.
Refractory particles Examples include: Chromite >0.2mm Carborundum >0.5mm	Inclusions (small particles not detectable)

The contamination issues listed above in Table 5.7 can potentially at a plant lead to a loss of 3 to 7 days flat glass production due to quality failure. This could entail a loss of 400,000 Euro to 900,000 Euro. [GEPVP, 2004]

5.3.2 Material market and flows of recycled material

About 495,000 tonne of automotive glass from ELV-vehicles is generated each year in Europe and available to be recycled. According to the minimum technical requirements for treatment of ELV vehicles in the ELV-directive, glass is to be removed from the vehicle to promote recycling.

For the past 25 years the standard glazing constructions for automotive vehicles have been laminated glass for the windshield and toughened glass for the side and rear glazings. According to Pilkington[5], it is expected over the next ten years that the type of glazings used in the side windows of automobiles will move from toughened glass to laminated glass.

Trienekens Rohstoff GmbH & Co. in Nivenheim, Germany, is a part of RWE Umwelt, which runs five glass recycling plants in the country. The Nivenheim plant is currently the largest glass recycling facility in the world. Each year, 70,000 tonne of flat/automotive glass are processed in the five RWE Umwelt plants. Half of the amount, 35,000 tonne, is processed in Nivenheim.

Recycled automotive glass is used within the following applications:

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[5] Pilkington is together with Saint-Gobain Vetrotex, and Glaverbel the biggest producers of automotive glass in Europe today.

- mineral wool industry
- bottle glass industry
- grinding products, construction material, glass beads, side rails
- foam glass (small fraction, under development). Up to 80 % of the foam glass on the German market is made of recycled flat/automotive glass.

The producers using recycled automotive glass charge about 22 to 55 Euro/tonne laminated glass, while toughened glass may be accepted for free. Though, one shall notice that the transportation cost is not included.

5.4 Thermoplastics

Thermoplastics are characterized having the property of softening or fusing when heated and of hardening and becoming rigid again when cooled. They could be strong and still lightweight, versatile and flexible. This enables the design freedom. Plastics can also improve the safety and durability of the vehicle, as well as reduce costs. Different plastics with different properties fulfil different needs. The amount of plastic in automobiles has increased and is still increasing. There are also differences depending on type of vehicle. Vans for example usually have a less percentage of plastic compared to sedans. Luxury automobiles usually have a higher amount compared to smaller vehicles. The plastic content in Japanese automobiles increased from about 3 % in 1973 to little more than 7 % in 1992 [Bouwman and Moll, 1998]. The composition of a typical European automobile year 2000 was 9.1 % plastics (104 kg) [Society of Motor Manufacturers and Traders Ltd, 2001].

The plastic composition in a Saab 900 from 1993;

- The most common plastics are PP, HDPE, and PUR. Together they stand for between 50 % and 75 % of the plastics.
- Common plastics are ABS and ABS/PC, PA, and PVC.
- Not so common are PMMA, POM, PPO/PS, PC/ASA, PPO/PA, ASA, PBTP, and Polyester.

The application of plastics in vehicles depends on the properties of the plastics. PP and PP/EPDM are used in the bumpers, different covers, fender-liners, air filter housing, instrument panel etc. HDPE is mostly used in the fuel tanks, ventilation channels etc. ABS and ABS/PC can be used in interior trims as door- and pillar-trims, instrument panels, displays, and in exterior parts as grille. PA is used, for example, in fans, wheel covers, engine beauty covers, cable channels, and electrical units in the engine compartment. PC can be used in interior lightings (the transparent parts). In some areas, as fender-liners and air-shields, most brands of automobiles are using the same plastic. For parts as instrument panel, door-trim, and headliner the material choice differs among different brands. Luxury automobiles usually include more expensive plastics than low budget automobiles.

Some plastic parts are dismantled for reuse when vehicles are scrapped today. Which parts depend on what the dealers have in storage and what the customers need. The batteries, which contain PP, are dismantled for recycling of the lead. In some areas, for example in Germany, there are recycling companies that also recycle the PP in the batteries. In Sweden, the PP is used for energy recovery. After vehicles are shredded, the automotive shredder residues, which contain almost all plastic, are disposed of in landfills.

Recycled plastics (recyclates) can be divided into the following categories, based on their origin:

- *Home scrap:* Those scrap materials, virgin material scrap, or by-products generated from and commonly reused by the industry within an original manufacturing process. Plastic regrind is an example of home scrap. This is usually not claimed as recycled content.
- *Post industrial recyclate:* in the production of a material or product that have been recovered or otherwise diverted from the waste stream for the purpose of recycling. This does not include home scrap.
- *Post consumer recyclate:* Those products or materials generated by a business or consumer that have served their intended end uses and that have been recovered from or otherwise diverted from the waste stream for the purpose of recycling.

Recycled plastics that are used in vehicles today are mostly from home-scrap or post-industrial scrap, but there are some examples also of post consumer scrap. Examples of post consumer scrap from vehicles that can also be used in vehicles are:

- The batteries are dismantled as a part of the pre-treatment process. The PP in the battery cover is then in some areas material recycled. The recycled material can be used as splashguards.
- Bumpers from repair shops are sometimes sold for recycling. The buyer of the bumpers requires that they are well sorted and not shredded to ensure the quality of the recyclate (PP, PP/EPDM).

Examples of existing or experimental recycling of the most common thermoplastics are described in this section. The market of recycled plastics is also discussed.

5.4.1 Recycling system and processes

Polymeric materials can be recycled in different ways. One category of processes is the *mechanical recycling* when the molecules in the polymer material are kept without any modifications. The traditional regrinding and remelting of thermoplastics belong to this category and so do the selective dissolution processes also.

Another category is *chemical recycling* where the molecules are broken down to smaller building blocks that can be used to build new materials. The chemical recycling processes includes some kind of a chemical agent that is adapted to the material to be depolymerized.

A third category is the *feedstock recycling by thermolysis* where the organic component of the polymer is converted by heat into high-value refinery products such as naphtha, crude oil, or syngas. The main forms of feedstock recycling by thermolysis are pyrolysis (process carried out in a reducing atmosphere, i.e. in the absence of air), hydrogenation (process carried out in a hydrogen atmosphere), and gasification (process carried out with a controlled addition of oxygen).

The mechanical and chemical recycling require rather ambitious sorting while the thermolytic processes can more easily be fed with mixed polymers, even shredder residues can be used to these processes. The polymeric fractions sent to the recyclers for mechanical or chemical recycling most often need some further sorting and washing as a start of the process to turn the material into defined usable material specifications.

The thermoplastics mentioned in this section are today mechanically recycled on commercial basis and methods are developed or under development to make recycling of shredder residue including these materials viable. Chemical recycling is not common but there are facilities to recycle PA6 carpets.

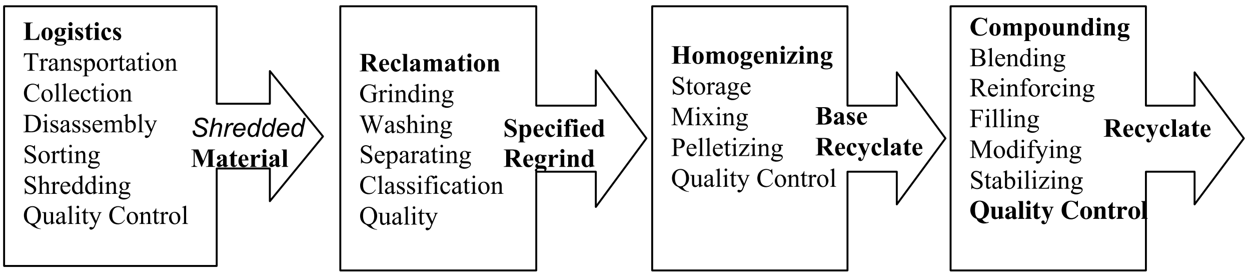

Figure 5.8. The figure shows the handling from used product to recyclate (recycled material) that can be used in a new product. All steps are not necessary for all products. The processes for virgin materials and recyclates differ in the steps before granulation [Luxus Limited, 2004].

Mechanical recycling

The main steps in mechanical recycling are explained in Figure 5.8 and the following text. To be able to recycle the material in a part from a vehicle, the part first has to be either dismantled or the material can be separated in an after shredder treatment process.

At the *pre-granulation processes (logistics and reclamation)*, when receiving plastic scrap for recycling, the recycler have to make sure that different polymer types are not mixed, metal parts and labels are removed, excess dirt and dust is removed and that the scrap is of suitable dimensions to fit the throat of the granulation equipment. The following list details the main processes involved.

- *Sorting:* Identifying components of differing polymer types to allow them to be processed separately and thus ensure the highest quality feedstocks.

- *Sawing:* When the components are too large to fit into the machines they have to be cut down to size.
- *Disassembly:* If the scrap is post-consumer or post-industrial, components that have been assembled into products can include metal components, different polymer types and plastic or paper labels. To maintain the quality of the resulting feedstocks, all of these extraneous items must be removed.
- *Shredding:* Shredding is a quick and efficient way of reducing large unwieldy plastic components into a manageable format. The process involves a spinning rotor that rips the plastic apart. The resulting output is irregular shaped, roughly cut product, which is generally still too large to use into the compounding processes (then it have to be grinded).
- *Washing:* Most of the scrap needs to be perfectly clean. Rinsing is also an important step of the washing line, especially if you use any kind of chemicals for the cleaning.
- *Separating:* Different plastics can then be separated by for example density separation or if the plastics have the same density you can separate them with for example froth flotation. The froth flotation [Argonne's Industrial Technology Development Division, 1998] technique uses the wetting characteristics of plastic materials as a basis for separating plastics, this is described in more detail in the chapter Skin flotation. Controlling the chemistry of a solution permits the wetting characteristics to be adjusted selectively. By changing the surface wetting characteristics of equivalent-density plastic materials, small gas bubbles can be attached to one material's surface, reducing its effective density. Because of the lower effective density of the bubble-plastic particles, the plastics will float in an appropriate solution.

Homogenization is the process of mixing multiple batches of the same polymer type (can also include process additives) to create a homogenous mix of product, to ensure a consistency throughout the resulting batch of material. After blending the material, further quality assurance checks are performed to ensure that the compound meets the required specification and quality criteria.

At the *compounding*, the material is transported along the length of the barrel via an Archimedes screw and is melted by applying heat by external heater bands, as well as the heat caused by friction (otherwise known as shear heat). As the material travels along, specially designed sections of the screw knead, mix and compound the plastic, and add additives and fillers. At the end of the barrel, the melted plastic flows through a wire screen that filters out any residual dirt, grit or other contaminants, and is then forced through a die plate. As the material comes through the die plate, it is cut into pellets and then cooled by quenching in water, and dried as it is blown around the pipe work and into packaging at the end of the line. The recycled plastic will only replace virgin if it meets the specifications. Shredding and grinding cause losses in physical strength, which can be compensated by adding virgin material.

The s*elective dissolution process* is also defined as mechanical recycling. The polymer is ground and fed into a container with a mixture of solvents that dissolve the polymer. The insoluble residues are separated and the polymer is precipitated,

dried, and conditioned. The solvents are regenerated and reused. This process works for PVC, ABS, and PMMA.
The mechanically recycled plastics can be divided into different categories depending on their shape and treatment history:

- *Regrinded:* Irregularly shaped and sized materials that result from grinding parts, sprues, runners etc. The material receives no further treatment, heat histories, or additives. Depending on the source and end use, regrind can fall into any of the three recycled content categories (home scrap, post industrial, and post consumer).

- *Repelletized:* Uniformly shaped and sized pellets that result from taking ground parts, sprues, runners, etc and running them through an extruder. The material receives an additional heat history and some contaminants can be removed with a screen but there are no additives. The material will either be post-industrial or post consumer depending on whether the source is industrial or consumer waste.
- *Recompounded:* Uniformly shaped and sized pellets that results from taking ground parts, sprues, runners etc and blend them typically in an extruder with virgin material and or additives. The material receives an additional heat history, some type of added material to improve properties and some contaminants can be removed with a screen. This material will either be post industrial or post consumer depending on whether the source is industrial or consumer waste.

Table 5.8. Sources of plastics that can be mechanically recycled.

Source	
Mixed unspecified post consumer plastics (for example: mixed bottles from households, shredder residue)	To get a specified material the plastics needs to be cleaned (washed) and to go through several separation steps. If you do not know the ingoing material you have to have enough separation steps to be sure that there are no contaminations left. Depending on the quality of the ingoing material different additives are necessary. Probably the material has to be re-compounded.
Mixed specified plastics, post consumer or post industrial (for example: bumpers from repair shops or manufacturer)	To get a specified material the plastics needs to be cleaned (washed) and separated. Less separation steps are needed if the ingoing material is well specified. The material probably has to be re-compounded.
Specified plastics, post consumer or post industrial (for example: caps from PET-bottles, Compact disc before metallization)	To get a specified material the plastics might need a washing step or it is enough with the extruding step where metals and other contaminants can be removed. Post consumer material probably has to be recompounded to add extra additives etc. The post-industrial material could be sold as regrinded, repellitized or recompounded depending on the specification.
Post industrial material (for example: sprues, runners, wrong coloured material etc)	To get a specified material this plastic usually do not need a washing step, but metals and other contaminants are separated. Can be sold as regrinded, repellitized, or recompounded depending on the specification.

Polypropylene (PP)
Present sources for PP are battery cases, car bumpers and dashboards from automotives (automobile dismantlers). Sacks, bottles strapping and industrial film scrap, crates, boxes and barrels from other areas. Also production scrap is used.

Markets for recycled PP[6] are for example different auto applications as splashguards (from battery cases), dashboard air ducts and air filter housings (from PP bumpers), air resonator, centre console, cable channels, fender-liner, housing fog lamp. Renault Megane RT used 100 % recycled bumpers in the bumpers.

Addition of stabiliser to the recycled PP is often necessary and recycled material is often mixed with virgin material. It is advisable to add a sufficient amount of antioxidant to last throughout the planned first, second and maybe even third life cycle already from start if the material is expected to be recycled. Antioxidants added to an already degraded material do not prolong the service life of the material. It is not advisable to recycle the material more than three times (if each cycle corresponds to approximately 5 years). Materials as PE are contaminating the PP. The result of the recycling is better if the used material is well known. This makes it easier to separate and clean the material to homogenous fractions of high quality. The recycling differs from the production of virgin materials in the first steps. The compounding step only differs in choice of additives. [Scheirs, 1998; Jansson, 2000]

High density polypropylene (HDPE)
Present sources are mostly bottles, but also motor-oil containers (e.g. Agip in Italy), and automotive fuel tanks (Solvay together with Renault). The market for recycled HDPE[7] is for bottles are motor oil bottles, pallets, garbage bags etc (usually blow moulded or extruded parts) and for fuel tanks auto applications as splash guard, air ducts, battery cover etc.
Today, HDPE is mechanically recycled. In those cases where the recycling fed is well specified and clean, recycling of HDPE works very well. In a recycling simulation, HDPE material could withstand up to ten simulated recycling steps (each cycle corresponds to approximately 5 years). Anti-corrosion coatings can contaminate the polymer and act as stress concentrators in the recycled polymer. Other contaminants could be PP which can cause de-lamination etc and PET which can plug melt delivery channels etc, metal fragments that could plug injection nozzles or catalyse polymer oxidation, pigments that could give undesirable colour variations, milk etc that can cause odour, other contaminants are paper, soil dirt, hydro-peroxides. Solvay, in collaboration with Renault, has developed a process for mechanical recycling of fuel tanks. When recycling fuel tanks the polymer can contain residues of fuel, which exert a plasticizing effect on the polymer, leading to increased values of elongation and yield. Residual fuel in the polymer at levels higher than 0.5 % can cause bubbles to form in new mouldings made from the recycled polymer. Impurities in the recycled HDPE polymer such as dirt and under-seal particles can lead to holes in the parison

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[6] Tradenames: ReFax (Himont), Palprop (Palplast), Seculene (BSB Recycling GmbH).

[7] Tradenames: R1000 and R2000 (Lyondell Polymers), Ecothene (Millenium Chemical Co), Retain (Dow), Fortiflex (Solvay Polymers), Exact (Exxon) etc.

during blow moulding. The polymer contains little or no antioxidant due to almost complete antioxidant extraction by the fuel. This makes re-stabilization of the polymer a necessity. The polymer can contain high levels of lead (from the petrol). The plastic fuel tanks generally contain metal inserts, which means that coarse shredding followed by metal removal is first necessary to protect the knives of the granulator from damage. A nylon barrier is used in some type of fuel tanks and this must be incorporated with the HDPE during reprocessing (it is dispersed into the HDPE recyclate). Blends of virgin HDPE mixed with 20 % fuel tank recyclate gives good Izod impact values, although not quite at virgin levels. The impact strength of recycled HDPE from fuel tanks is 70 % of that of virgin HDPE [Scheirs, 1998].

Acrylonitrile butadiene styrene (ABS)
Present sources are vacuum cleaner housings, automotive radiator grills, computer housings, plant scrap from part suppliers and toll compounders. Market for the recyclates of ABS[8] is, for example, automotive interiors and automotive radiator grilles (from dismantled automobiles).

Recycling of ABS is often economically, because of the god properties and the price of the recycled material. The recyclability of injection-moulded ABS components has been investigated. It was found that ABS maintains its properties well after reprocessing apart from a slight decrease in the notched Izod impact strength. Mechanical properties such as tensile strength, elongation and hardness are essentially unchanged after repeated processing, however there are an increase in yellowness. ABS with the highest butadiene content exhibited the highest rate of yellowing. ABS with the highest butadiene content underwent the greatest loss in impact strength [Scheirs, 1998].

Polycarbonate (PC)
Present sources are milk bottles, Compact Discs (both used and production scrap, with or without metallization), thermoformed trim scrap and plant scrap. Plant scrap could be from the production of autos. Markets for recycled PC[9] for automotive applications are instrument panels, headlight reflector bodies, loudspeaker box, rear light box and interior lamp housing.

The recycling is often economically, because PC is a high price polymer with good properties of the recycled material. Less than 5 % change in properties compared with virgin [Scheirs, 1998]. The used CDs are not suitable for new CDs (the extremely stringent requirements can not be met in a cost-efficient manner) [Bayer material science, 2004].

Polyamide (PA)
Common polyamides are PA6 and PA66. Nylon is a trade name for polyamide. Present sources are plant scrap from part suppliers and toll compounders, used

[8] Tradenames: Remex (GE), Cyclolac (GE), Retain (Dow), Ekanyl (Sattler), Palran (Palplast), Dylac R (Hoffmann & Voss). Some of these companies are also selling ABS+PC.

[9] Tradenames: Remex (GE), Lexan (GE), Naxell, Bayblend R (Bayer, ABS/PC), Ekalon (Sattler) and PC R (Bayer), Palsafe (Palplast)

truck radiators, and carpets (almost only from buildings). Market[10] for the recyclate in automobiles is engine beauty cover, wiring ducts, brackets, covers, air cleaning houses (from carpets), and caps for oil filter.

There is very little reduction in mechanical properties when nylon recyclate is blended with virgin nylon even at high levels. Unreinforced grades of recycled PA exhibit excellent melt stability and regrind levels as high as 50 % can be used. For reinforced grades of Nypel (Allied Signal), regrind levels of 25-30 % are generally recommended because higher levels may show decreased properties due to excessive glass-fibre breakage [Scheirs, 1998]. Sometimes up to 100 % of recycled nylon could be used. In a joint project between MB AG and Bayer they tested to recycle coach seat backs and make fan shrouds of the recycled material. The tests showed god properties with 25 % of recyclate. With 50 % and 100 % recyclate the notched impact strength decreased [Bayer material science, 2004].

Acrylonitrile butadiene styrene / Polycarbonate (ABS/PC)
Present sources are mostly plant scrap from for example production of auto parts. Markets for recycled ABS/PC[11] are for example different housing in vehicles.

Today, ABS/PC is mechanically recycled. ABS and PC can be blended to enhance certain properties. If ABS contains antimony trioxide or halogenated flame-retardants this can cause a depolymerization of PC. The PC-ABS recyclate blends have properties comparable to those of the virgin resin.

Feedstock recycling
At *feedstock recycling*, the organic component of the polymer is converted by heat into high-value refinery products such as naphtha, crude oil, or syngas. The main forms of feedstock recycling by thermolysis are pyrolysis (process carried out in a reducing atmosphere, i.e. in the absence of air), hydrogenation (process carried out in a hydrogen atmosphere) and gasification (process carried out with a controlled addition of oxygen).

The thermolytic processes can be fed with mixed polymers, even shredder residues can be used to these processes. It is unclear which of these process that will be classified as recycling or recovery. According to an Öko-Institute report the costs for syngas production and blast furnace is estimated to be lower than for mechanically recycling but still more expensive than land filling or incineration [Jenseit *et al.*, 2003].

The *Montello process* concept maximizes the recovery of the heat content of shredder residue. The SR (excluding fines) is gasified in a rotary kiln producing a fuel gas, which is used to heat the metal scrap that is charged into an electric furnace. The furnace produces steel rod and bars for concrete reinforcement. A pilot plant was in process some months between 1993 and 1996. The return of investment that was calculated for 9 years showed a satisfactory return. [ELV network, 2004]

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[10] Trademarks: Nypel (PIR, Allied Signal), Pentamid (Pentac), Palmid (Palplast), Signy (Polyamid 2000 AG).

[11] Tradenames: Dyblend (Hoffmann Voss), Palblend (Palplast)

Work on a small pilot scale has shown that feedstock recycling of ASR by *fluid bed pyrolysis* and subsequent de-halogenation is feasible. The plastics not dismantled for mechanical recycling could be turned into petrochemical feedstock reusable in the steam-cracker cycle. The main concern for the by-products is the chlorine content, which could be solved by de-halogenation. Evaluation of the economics of the process has shown that, for a 40,000-tonne/year plant, cost is comparable to mechanically recycling. [ELV network, 2004]

SVZ (Sekundärrohstoff-Verwertungs-zentrum Schwarze Pumpe) is engaged in the eco-efficient processing of solid and liquid wastes in accordance with German recycling and packing-material laws. In the SVZ plant, shredder residues are *gasified* with coal or other waste materials in a moving bed gasifier. The SR has to be pre-treated in to make a cylinder of about 8 cm diameter or smaller, depending on the gasifier type, prior to feeding it into the gasifier. Its annual processing capacity is about 450,000 tonnes of solid waste and 50,000 tonnes of contaminated oil and oil-water emulsions. The estimated gate fee for SR to be delivered to the site in cylinder form is around 75 Euro/tonne. SR is pre-treated at the shredder via a compactor, which reduces transportation costs but is rather expensive [ELV network, 2004].

Pyrolysis using Siemens-KWU, the *Schwel/Brenn process*, is initially designed for MSW and is a two-stage process that combines pyrolysis and combustion with energy recovery. Tests by Bayer showed no limitations for SR and no need for a pre-treatment step. For a commercial MSW plant with a capacity of 150,000 tonnes/year costs are estimated at approximately 150 Euro/tonne. The plant was shut down but the technology has been licensed to Mitsui in Japan. [ELV network, 2004]

Chemical recycling

A specific method of feedstock recycling is chemical recycling where step-growth polymers react with chemicals to recover monomers. Polycarbonate, polyesters, and nylons belong to the family of step-growth polymers. Step-growth polymerisation are reversible reactions. This gives the opportunity to process this type of polymers in such ways to recover their monomers, i.e. they can be chemically recycled [Margon, 2004]. Polymers that are chemically recycled today are PA6, POM, and PET (DuPont has also developed and patented a process for PA66).

To achieve chemical recycling, polymers must be decomposed in high yield into useful feedstocks with a view to obtaining monomers that can be reused for manufacturing new polymers. This step is usually more difficult than conversion into fuels (feedstock recycling by thermolysis). In other words, chemical recycling requires cracking catalysts with selectivity much higher than those required for fuel recovery. Recycling chemically includes most of the steps that are needed for mechanically recycling as for example, sorting, shredding, washing (depend on process), and separation. Then the material is depolymerised and polymerised. The extra steps ads costs to the chemical recycling. When the chemical recycling results in the original monomer, such as caprolactam for PA6, the monomer can be polymerised again to the original plastic, such as PA6. The quality depends on the purity. With high purity the new PA6 have the same properties as the original PA6.

Polyamide (PA): Chemical recycling by hydrolysis
Present source is mainly carpets (almost only from buildings). The produced caprolactam can be used to produce new polyamide.

PA6 can be hydrolytically depolymerized in an aqueous system under pressure to give high yields (60-70 %) of caprolactam (the monomer of PA6). Higher reaction temperatures give enhanced yields of caprolactam. Although no catalyst is necessary for this process, removing water from the caprolactam requires distillation and is relatively expensive. If higher temperatures, then higher pressure which means higher capital investment costs (to achieve yields over 70 %) [Scheirs, 1998].

Polyamide (PA): Chemical recycling by acidolysis
Present source is mainly carpets (almost only from buildings). PA6[12], polymerized from caprolactam (depolymerized from recycled PA), can be used in new products for different applications.

The acidolysis of nylon 6 can be efficiently catalyzed by phosphoric acid and give a reasonable yield of caprolactam and refining the reaction products is easily accomplished. Some shortcomings limits its commercial use; the fillers or fibre reinforcement in the polymer can react with the acid catalyst lowering the efficiency of the process, the high cost associated with consumption of catalyst and expensive treatment of by-products and waste-water. These limitations can be overcome by separation of fillers/fibres from the polyamide [Scheirs, 1998].

Polyamide (PA): Chemical recycling by ammonolysis
Present source is mainly carpets (almost only from buildings). New nylon monomers (caprolactam) can produce new PA6 and PA66 and then for example new carpets or other products.

Du Pont has identified ammonolysis as the best depolymerization option for scrap carpet. PA6 and PA66 react with ammonia and a phosphate catalyst to produce PA monomers. The nylon monomers can produce new PA6 and PA66, which can be spun into bulked continuous filament to produce new carpet. The cost of the nylon made of recycled monomer is more expensive (25 % higher than virgin) but the demand for nylon products with a high PCR content is expected to offset the expense [Scheirs, 1998].

Polyamide (PA): Chemical recycling by depolymerization in vacuo
Present source is mainly carpets (almost only from buildings). The produced caprolactam can be used to produce new polyamide.

PA 6 can be depolymerized in vacuo to give good yields of caprolactam (in excess of 80 %). This method of depolymerization is particularly attractive in that the caprolactam end-products is of high purity and no distillation of water is

[12] Tradenames: Perlamid (Polyamid 2000 AG).

necessary in contrast to the hydrolytic depolymerization method. Advantages over hydrolytic depolymerization; higher yield of caprolactam (15 % higher), high-purity caprolactam is produced, a short reaction time allowing higher throughput and distillation to remove water is not necessary. A catalyst is necessary and it is important that the catalyst is evenly distributed throughout the polymer to avoid inhomogeneous reactions, residues of fillers, polymer and catalyst must be disposed of, and the organic residue that is produced can not be fed back into the process, since tar formation can result [Scheirs, 1998].

Energy Recovery
Polymeric material can also be energy recovered by different methods such as cement kiln, waste incineration, and blast furnace.

The plastic fraction in the shredder residue (with high heat value) could replace the heat from coal and lignite in *cement kilns*. The fluff has to be further separated. The plastic fraction in the shredder residue (with high heat value) can also be *co-combusted with municipal waste* to produce steam and electricity.

In a *blast furnace*, material of high calorific value may be used to substitute heavy fuel oil or coal [Jenseit *et al*., 2003]. Plastics also function as a reducing agent blown in the bottom of the blast furnace. The plastics in the fluff from shredding have to be separated from the SR, before agglomeration and usage in blast furnaces.

Shredder residues (SR) can be used in *non-ferrous metallurgy*. The extraction of base metals from sulphide ore by modern processes uses very little extra fossil fuel. However, at secondary smelters more fossil fuel is used for smelting, offering the potential for primary fossil fuels to be replaced by SR. The SR is more attractive if it contains about 10-15 % copper or other metals with similar value and less attractive if it contains elements that induce extra costs during melting and refining. The use of shredder residue is currently unattractive due to the excess amounts of energy contained and the amount of slags generated. [ELV network, 2004]

Pre-treated SR can be *feedstock recycled in the blast furnace process*. Organic shredder residue components in the form of shredder granulate and agglomerated shredder fluff (overall yield 50 %) can be used as a reducing agent in blast furnace processes. Converted to hydrogen and carbon monoxide they react with iron oxide to produce metallic iron, carbon dioxide, and water (steam). Small quantities of shredder residues, after mechanically treatment, have been blown into the blast furnace without problems. Cost is calculated to 250 Euro/tonne. [ELV network, 2004]

Cost comparison of different recovery options
Different recycling alternatives of bumpers made of PP are studied from the cost and environmental perspective in an Öko-Institut study [Jenseit *et al*., 2003]. The estimated costs and revenues for different scenarios of handling used bumpers are showed in Table 5.9. The studied examples are to send the material to a landfill, to waste incineration, to use it in cement kiln, to use it for syngas production, to use

it in a blast furnace or to recycle it mechanically either by diverting the material from shredder residue (Galloo) or by dismantling the bumper (dismantling).

Table 5.9. Results of cost calculation for different recycling scenarios of a bumper (Euro/part) [Jenseit *et al.*, 2003]. The bumper is made of PP and the weight is 3.14 kg.

	Land-fill	Waste incine-ration	Cement kiln	Syngas pro-duction	Blast furnace	Min – mechan. recycling (Galloo)	Max – mechan. recycling (Dismant-ling)
Trans-portation	0.016	0.010	0.029	0.029	0.144	0.087	0.087
Shredder	0.021	0.020	0.020	0.020	0.019	0	0
Processing / Compounding	0	0	0.321	0.321	0.321	1.236	1.236
Dismantling	0	0	0	0	0	0.750	1.202
Gate fee	0.221	0.323	0.076	0.229	0.159	0	0
Revenues	0	0	0	0	0	-1.272[13]	-1.272
Others	0	0	0.011	0.016	0.033	0.039	0.039
Total	0.259	0.353	0.458	0.615	0.676	0.840	1.292

In the examples, there is an estimated revenue for the mechanically recycled bumpers that is below the estimated costs. The revenue can exceed the cost if the part does not have to be dismantled or is dismantled by other reasons. Another sort of revenue is the avoidance of landfill fee or incineration costs. In this example, recycling of the bumper without the dismantling step would cost 0.09 Euro (The total cost for Recycling with Dismantling is 0.840-Dismantling 0.750 gives a cost of 0.09), which is a less expensive alternative than to landfill the part.

5.4.2 Material market and flows of recycled material

The price of virgin plastics differs depending on properties and market demand, as well as production costs:

- Low cost plastics are PP, PE, PS and PVC, mostly around 1 Euro/kg or less.
- Medium priced plastics are ABS and PA, mostly between 1.5 to 2.5 Euro/kg.
- More expensive plastics are PC and POM, mostly between 3 to 4 Euro/kg. POM is less expensive than PC.

The price of virgin material is changing with the oil price, more or less depending on material, e.g. more for low-cost polymers as PP than for PC. This is because the price margin between a low-cost polymer and oil is less than for a more expensive polymer. The price of recycled plastics (mechanically recycled) is usually lower than for virgin plastics, see Table 5.10. The price depends on the quality of the recyclate (i.e., which specification it fulfils) and the recycling

[13] Revenues for the non compounded material from bumpers are approximately 0.46 Euro/kg [Grannex, 2002]. The compounding step of the plastics from a bumper is about 0.25-0.3 Euro/kg.

process, i.e., if the material is cleaned, regrinded, or compounded etc. Usually repellitized material is more expensive than regrinded/flakes, and re-compounded more expensive than repellitized because each step add extra costs. Post-industrial recyclate is usually of better quality than post consumer recyclate, and the recycling process is also less expensive. To be able to sell the recyclate, post-industrial or post-consumer, it still needs to be less expensive than the virgin material (with exception for, for example some chemically recycled PA6 which have the same properties as virgin). The price depends not only on process etc but also on the quality. The differences in price between virgin and recycled plastics are usually higher for more expensive plastics than for low cost plastics.

Table 5.10. The table shows the prices for different recyclates compared with the price for the virgin material, e.g. the price for post consumer recyclate (PCR) pellets for HDPE natural is approximately 66 % of the virgin material price. PIR is an abbreviation for post-industrial recyclate. [Anonymous, 2004; Plastics news, 2004; Plastics Technology, 2004; Pro-plast, 2004]

	PCR/virgin							**PIR/virgin**					
	Pellets / virgin, Sep 2003	Pellets / virgin, Jan 2004	Pellets / virgin, 1996-99	Pellets / virgin, 1996-99	Clean flake / virgin, Sep 2003	Flake / virgin, 1996-99	Flake / virgin, 1996-99	Pellets / virgin, Sep 2003	Pellets / virgin, Jan 2004	Pellets / virgin, 2002	Clean flake / virgin, Sep 2003	Clean regrind or flake / virgin, Jan 2004	Clean regrind or flake / virgin, 2002
HDPE (Natural)	0.66	0.66	0.67-0.89	0.71	0.42	0.52-0.68	0.56						
HDPE (Mixed colours)	0.54	0.53	0.59-0.70	0.57	0.37	0.42-0.57	0.44		0.50			0.36	
PP	0.26		0.55-0.72	0.63		0.32-0.60	0.49	0.46	0.40		0.34	0.28	0.72
ABS (Mixed colours)									0.58			0.49	0.60
PC (Clear)										0.65		0.52	0.52
PC (Mixed colours)									0.35	0.65			0.52
PA6										0.88			0.44
PA66										0.64			

In vehicles, recycled plastics are mostly used in black exterior parts as fender-liners or air-shields, but also as for example engine compartment parts as beauty covers. The trend is to find new applications, which include also interior parts, see Figure 5.9.

	Exterior non-visible	Exterior visible	Under the hood	Interior non-visible	Interior visible
Require-ments	- Satisfactory mechanical properties	- Surface and UV-stability	- Heat resistance - Good mechanical properties - Oxidative stability	- Little odour - Good mechanical properties - Heat resistance	- Little odour - Excellent surface scratch resistance - Colour application
Examples of appli-cations	- Fender liner	- Cowl	- Air cleaner box - Cable channels	- Nozzle - Air channels	- Glove box - Door panels - Trim shroud panel - Centre console

Figure 5.9. This is an example from the supplier Polymer-Chemie on how the usage of recyclates improves [Polymer-Chemie GmbH, 200X].

To be able to sell recyclates for automotive parts it has to be a well specified material that will fulfil a certain specification. The recycled plastic can only replace virgin plastic if they could meet the required specification. The source and quality of the shredded material decide which processing steps are necessary and which additives (including virgin material) that are needed to fulfil a certain specification. The usage decides which specification the material must fulfil. The figure above shows that for example the material in a fender liner has to have satisfactory mechanical properties[14] but if the material is going to be used in the engine compartment it must have good mechanically properties and also be heat resistant. If you need a transparent material the source for the recyclate have to be transparent but for black parts the original colour usually does not matter. Specific colorants can give the material the right black colour.

The ELV directive will reduce the amount of plastics from vehicles that are land filled. It will also increase the recycling of plastics, to fulfil the requirement of 85 % material recycling. To further increase recycling of plastics the revenue minus cost have to be higher than recovery (or landfill). If post shredder technologies improve and are economically viable the usage of recyclates can be increased also from shredder residues.

The dismantled materials usually have some value, but today dismantling time and storage cost usually exceed that value. The recycling company usually requires that the parts for recycling are complete (not shredded) and that will take a lot of storage space and also result in higher transportation costs. The recycling

[14] Depending on which markets the vehicle is sold on, the requirements are lower for an automobile that is only sold in Europe compared with one that will be sold to both north countries and in warm and humid areas as, for example, Florida.

could be economically when the parts have to be dismantled for other reasons, as for example pre-treatment or repairing, as the earlier mentioned PP in battery cases and PP and PP/EPDM in bumpers from repairing shops, if the transportation and storage, together with processing and compounding is less than the price of the recyclate. To improve the usage of recyclates there is a need for more cost efficient ways of sorting the material to enough specified fractions. After shredder residue-sorting processes might solve this problem.

If dismantling becomes more economically compared to post shredder residue sorting, parts that could be suitable for dismantling are: fender-liners (PP), air-shields (PP), engine beauty cover s (PA), rocker panels (PP), sill covers (ABS), wheel covers (PA), pillar trims (ABS), air cleaners (PP) etc. These parts are usually easy to dismantle, made of a single material, and have some weight.

5.5 PVC

PVC, polyvinyl chloride, is a thermoplastic that differs from other thermoplastics by containing chlorine. The chlorine stands for around 56 % of the weight of the PVC molecule. PVC is rather heavy (1.4 g/cm^3), and without a plasticiser stiff (modul 2.5 GPa), strong (tensile strength of 50 mPa) and has high impact strength.

PVC has an advantage compared to other plastics in that it easily mixes with additives such as plasticisers, stabilisers etc. This gives the material a wide range of use. It can be used for rigid products such as pipes, profiles, window frames and for soft products such as cable insulation, floor mats and vehicle interior materials. Within the automotive industry, PVC is used for e.g.

- Underbody coatings, sealants and floor modules.
- Wire harnesses (e.g. cable insulation and grommets).
- Passenger compartment parts (e.g. dashboard and door panels and arm rests)
- Exterior parts (e.g. body side protection strips, weather strips and window sealing profiles).

5.5.1 Recycling system and processes

The options for waste management of PVC are: mechanical recycling, feedstock recycling and energy recovery. The appropriate option, in relation to ELVs, is closely linked to the characteristics of the component itself, particularly in terms of size and complexity.

Mechanical recycling

Mechanical recycling of plastics is the reprocessing of used products into new ones. An important requirement, however, for successful mechanical recycling is a waste stream of sorted materials of the same types and to have these in sufficient quantities to be commercially viable.

The technical potentials of the mechanical PVC recycling are determined by the achievable quality of the PVC recyclates. To be used for the production of new products, recyclates must comply with a set of technical specifications which in the end refer to the contamination and the composition of the recyclates.

Some issues to consider when it comes to mechanical recycling of PVC:

- Much more than other commodity plastics (such as e.g. polyethylene and polypropylene) PVC is a compound material. This means that it does not consist of polymer PVC alone but includes also a variety of additives such as stabilizers (to avoid degradation of the PVC), plasticizers (in flexible PVC), fillers, impact modifiers, pigments, and processing agents.
- Each PVC application has its specific material composition.
- Also for a specific PVC application, the composition of the PVC compounds can differ depending on the producer or processor. Furthermore, the composition of the PVC compounds for a specific application has changed in time due to technological changes, e.g. today window profiles are produced from different PVC compounds than window profiles 20 years ago.

Even by separate collection of PVC wastes by type of product it is hardly possible to gain PVC material of an exactly uniform composition. For pre-consumer wastes it may be possible to recover material of a defined composition (if for example a cable layer returns cut-offs to his specific supplier). This is however not the case for post-consumer wastes.

Mechanical recycling can be carried out using post-use PVC products that are clean, easy to identify and separate from the waste stream. PVC composites can sometimes be recycled. Examples of products are industrial flooring and "leather cloth", which can be recycled into moulded mats and carpet backings, respectively.

Example of pre-consumer recycling
In general the recycling of pre-consumer wastes yields high-quality recyclates. A part of the recyclates can be used by the PVC compounders or processors as an equivalent for virgin PVC. The other part can be used for example as separate layers in co-extruded PVC-products (e.g. profiles with a core of recyclates) or as backing material of floorings[15].

The recycling costs for pre-consumer wastes vary depending on the specific case and type of wastes. Thus no general valid cost figure can be given but only an order-of-magnitude of the recycling costs. According to published information [Brandrup, 1995; GUA, 1998] the following cost ranges can be given (per tonne of recyclate output):

- collection, sorting and transport: 100-150 Euro/tonne
- treatment (re-granulation): 270-500 Euro/tonne,

where the lower limit of the treatment costs applies for pure plastics wastes (without contaminations) requiring grinding and extrusion operations only, and the upper limits for pure plastics wastes with contaminations requiring additional

[15] i.e. it replaces virgin PVC, but not "1:1", for example due to unspecified colours.

washing, drying and separation operations. Thus total recycling costs may vary between 370 and 650 Euro/tonne. For grinded material (without extrusion) the costs may be 100 Euro/tonne lower. Today, the achievable prices for grinded PVC recyclates range from about 200 to 450 Euro/tonne depending on the quality (esp. specified white colour or not). [EU, 2000]

Thus pre-consumer recycling is not profitable in all cases today. Mainly pure material fractions (PVC fractions without contaminations), which do not require extensive treatment to yield high-quality recyclates are required to reach profitability. However, the prices for virgin PVC are at a very low level at present.

Example of post consumer recycling
Post-consumer PVC cable insulations arise as a waste fraction in the mechanical recycling of cables. It is a mixed plastic fraction containing about:

- 80 % PVC compounds (ca. 50 % of pure PVC and 50 % plasticisers, fillers and other additives, e.g. lead stabilizers),
- 20 % other plastics, such as polyethylene, including about 2 % of contaminations (e.g. residual metal content). [EU, 2000]

The plastic fraction is available in its final form for extrusion into new products. Generally the material is used by plastics processors, e.g. for the extrusion or injection moulding of plastics products, without extensive prior mechanical operations. The material is used for applications similar to the products of mixed plastics recycling, e.g. poles for roads and industrial floorings. [EU, 2000]

PVC cable insulations are recycled for pure economic reasons, i.e. the recycling is a competitive or near-competitive waste management option. Therefore, the recycling activities fluctuate with the price for virgin PVC and the prices for alternative waste disposal options for the PVC wastes.

The primary objective of cable recycling is the recovery of the copper content of the cables. The costs of cable collection and treatment are therefore, for the cable recycler, attributed to the primary outputs of cable recycling, i.e. copper and other metals (e.g. aluminium). The PVC waste fraction is a cost factor only. Thus its recycling is profitable as soon as transportation costs plus/minus costs or credits for the processing (extrusion) of the material to new products are lower than the cost for incineration, land filling or possibly energy recovery (including transportation). The presence of metals residues in the plastics fraction prohibits the recycling as cable insulations.

Based on information of interviews with recyclers [EU, 2000], the order-of-magnitude of the costs are estimated as follows:

- The total net cost ex cable recycler is lower than 50 Euro/tonne, which is the present fee to be paid by cable recyclers to traders or processors.
- The costs of the plastic processes using the recycling material differ depending on the products that can be produced and the processing technology. The net costs (processing costs for extrusion or injection moulding minus proceeds for the final products) are around 0. In some cases

the processor gets a fee for taking over the material, in some cases he pays for it.

- Trading of the material even over longer distances is economically attractive in some cases. An example is the export from Germany to the UK, where the transportation costs are nearly covered by the reimbursements of the processors. In addition, the cable recycler in Germany pays a fee, which is well below the prices for land filling.

Feedstock recycling
Feedstock recycling is better suited for complex products than mechanical recycling and should be seen as a complement. Examples of products that can be recycled with this technology are laminated films, "leather cloth", footwear and car dashboards.

For PVC waste that is low in chlorine content, e.g. flexible PVC: The pre-treatment steps include sorting or separation which is done by dilution of excessive chlorine or thermal dehalogenation. The second step is "thermal cracking" via hydrogenation, pyrolysis or gasification. The produced hydrochloric acid is neutralised or separated for industrial use.

For PVC waste that has a high chlorine content, e.g. rigid PVC (>30 %), the process is different. These processes are still in early development and include high temperature incineration in a rotary kiln, gasification in a metal or slag bath, or pyrolysis in a circulating fluidised bed. The HCl output has to be purified so that it can be used for making new PVC. The economic viability of these processes is still somewhat insecure.

Energy recovery
Energy from ASR can be recovered through incineration together with household waste in MSW incinerators or as a fuel in cement kilos.

Research conducted in MSW incinerators have recently concluded that PVC not specifically contributes to the formation of dioxins when incinerated in a modern incineration plant for household waste. The quantity of dioxins depends instead upon the incineration conditions. High dioxin concentrations can e.g. be caused by an incorrect incineration temperature. The quantity of chlorine is not the limiting factor here, since there is a large surplus of chlorine when incinerating household waste.

When PVC is incinerated hydrochloric acid (HCl) is formed. This can cause problems with corrosion in the furnace. In order to avoid this problem, the formation of hydrochloric acid calls for an increased capacity for neutralizing the flue gas. This is a reason for why many municipalities do not want to incinerate PVC in their refuse disposal units. The PVC waste is then referred to the incineration plants for hazardous waste, which leads to an increased cost for getting rid of the PVC waste.

It is most likely that the high costs for incineration (as hazardous waste) will result in a driving force to develop new waste management processes for PVC.

Environmental issues
Many environmental disadvantages of PVC, compared to other plastics, have been discussed over the years. Leakage of heavy metal stabilisers and the formation of dioxin when incinerated (see above) are examples of issues that have been discussed.

The vinyl chloride monomer, the basic building block of PVC, is a carcinogen and can cause cancer when breathed in high concentrations over a long period of time. When this was discovered, the exposure of vinyl chloride in the production plants were 100 ppm or higher. After the correlation between vinyl chloride and cancer had been done, the PVC industry has reduced the exposure to less than 1 ppm and has reduced the emissions of vinyl chloride to the environment.

In Europe the PVC-industry has, within the program Vinyl 2010, invested in developing new technology for recovering post-consumer PVC. Within the program, efforts have been made to develop the mechanical recycling technology further (e.g. for pipes) but also to develop a cleaning technology for removing different additives such as e.g. softening agents and stabilizers. In addition, attempts with different processes for chemical recycling are conducted. Over the next 10 years there will be many new technologies available to the recyclers.

5.5.2 Material market and flows of recycled material

In 1999, the total volume of available PVC waste was about 4.1 million tonnes, of which 3.6 million tonnes were post-consumer PVC wastes and 500,000 tonnes were pre-consumer PVC wastes. 11 % of this volume came from the automotive industry. [EU, 2000]

The PVC consumption in EU was in 1999 about 7.4 million tonnes, of which about 60 % was used within building products and 7 % within the automotive industry. On a compound-basis
about 50 % of the PVC applications in EU are flexible products and 50 % are rigid products. About 520,000 tonnes of pre-consumer and post-consumer PVC wastes are recycled in EU today [EU, 2000]:

- about 80 % (420,000 tonnes) of the recycled PVC wastes are pre-consumer wastes. This represents about 85 % of the pre-consumer PVC waste arising.
- recycling of post-consumer PVC wastes is still at a very low level in the EU. Today about 100,000 tonnes of PVC wastes are mechanically recycled. This represents about 3 % of post-consumer PVC waste arisings.
- the major part of post-consumer PVC recycling is in the areas cable wastes and packaging wastes. Cable recycling and a considerable part of packaging recycling are mixed plastic recycling, i.e. recyclates with a low quality are produced.
- high-quality mechanically recycling for post-consumer PVC wastes (i.e. production of pure PVC recyclates) exists for single product groups (bottles, pipes, window frames) only, with very low quantities yet.

There is a close linkage between the recycling market and the market for virgin PVC. The recycling activities fluctuate with the price for virgin PVC to some extent. If virgin PVC prices are down the economic feasibility of some of the recycling activities ceases and they are stopped until the virgin PVC prices exceed a certain level again. In Italy, the production of PVC recyclates fell from about 120,000 tonnes to 110,000 tonnes between 1997 and 1998, as a result of the drop of PVC prices. [EU, 2000]

5.6 Composites

Composite materials have considerable potential for improving the performance of transport structures by reducing weight, providing good corrosion resistance, and enabling cost-effective processing. The composites are materials composed of a matrix with fibre bundles as reinforcement. The matrix may be metallic, polymeric, or ceramic. Here, only polymeric composites will be considered.

The most common thermoplastic matrixes within the automotive industry are polypropylene (PP), polyamide (PA), ABS, and PC+ABS. Typical reinforcements are glass fibres, mineral filler (talcum), and vegetal fibres. The most common thermoset matrixes within the automotive industry are polyester, PVC, and polyurethane. Within the automotive industry, composites are used for e.g:

- Noise shields
- Underbody shields
- Frontend
- Bumper beam
- Instrument panel
- Doors.

Some common abridgements used for groups of composites are:

- FRP - fibre reinforced plastic
- GRP - glass fibre reinforced plastic (most often thermoset ~ SMC)
- CFRP - carbon fibre reinforced plastic (thermoset)

World production of FRP is ca 4.2 million tonnes per year [ReFiber, 2003]. Some of the most common composites are presented below.

SMC and BMC

SMC, Sheet Moulded Compounds, and BMC, Batch Moulding Compounds, are thermoset plastics reinforced with glass fibres and fillers. The plastic is cured to its final shape and after the curing, the plastic is not remeltable. The most common plastic matrix is polyester. Epoxi, vinylester and acrylates are also used. SMC is the most common composite type, the volumes are much greater than carbon fibre reinforce plastics (CFRP).

The automotive industry is the biggest user of this material group (where SMC is much more common than the courser parts that are classified as BMC) and boats and wind mills are other big users. The life lengt is predicted 10-50 years and big amounts of post-consumer composite waste are expected soon. So far small amounts have been material recycled, e.g by ERCOM, and many methods are practically possible but the economical feasibility has not been demonstrated. The biggest problem is the lack of demand to use the recycled composite in a new application

The glass fibre content normally varies between 25 to 55 weight%. The manufacuring process give suitability for relatively small parts with big series production. In most applications it is possible to save 20 to 50 weight% of the product compared to steel constructions.

GMT
GMT, Glass Mat Reinforced Thermoplastic, is a thermoplastic matrix (e.g. PP, PA, PET) reinforced with orientated or random glass fibres of various lengths. The biggest use are within the automotive industry; frames, front parts etc.

GMT is often manufactured with prepregs that are heated and moulded, or with plastic granulates and glass fibres that are mixed with additives and heated and moulded. Post-consumer waste are harder to material recycle due to less knowledge of material content and properties, but it is not impossible.

PP/flax
PP/flax is polypropylene thermoplastic reinforced with flax fibres. The use of this material has increased since it has good mechanical properties and is renewable, biodegradable and combustible.

CFRP
CFRP, Carbon Fibre Reinforced Plastics, are used when materials need to combine high strenght with low weight (e.g. aircraft, space and yacht designing). The carbon fibres are about 10 times as expensive as glass fibres, but the constructions can be made lighter.

Thermosets are used as matrix, epoxi or vinylester are the most common. Since the raw materials are more expensive, the driving forces to recycle the composites should be higher, but the CFRP waste fractions have probably not been large enough yet.

Sandwich constructions
Sandwich constructions are used in many applications, mainly in aircraft and space industry but also for marine constructions and train applications. They are made of two thin, strong faces bonded (with adhesive or welding) to a weaker flexible core. The faces carry the compressive and tensile stresses that arise in bending. The core carries the shear stresses and keeps the faces at constant distance. This leads to that the sandwich derive outstanding bending strength and flexural stiffness, combined with low weight.

The faces can be fibre reinforced plastics, plywood or metal sheet. The core can e.g. be made of a rigid polymer foam, a honeycomb structure or balsa wood. The weakest spot is the adhesive bonding between the faces and the core; if delamination occurs the construction looses its strength. Techniques to do reinforcement in the core connected to the faces without any joints, removes this problem.

The core in the sandwich can contain a high fraction of recyclate. Some tests have been made in the middle of 90's to demonstrate the recyclability of thermoset composites. The interest from the market and the industry was limited. For more information see Larsson [2004] in Appendix J.

5.6.1 Recycling system and processes

Composite materials cannot be easily recycled in the same way as un-reinforced thermoplastics. Instead it is necessary to develop dedicated recycling technologies. Several techniques have been studied in detail over the last 10 years. Information about these techniques is given below.

Recycling of thermoset composites is complicated by the presence of the glass fibre reinforcement, and the cross-linked nature of the polymer matrix. A simple re-melting and re-use is not possible, as with un-reinforced thermoplastics. Fibre reinforced thermoplastic composites can in principle be reprocessed, but the reinforcement is again a problem.

There are two types of composite waste:

- Production waste: generated during production of composite products at manufacturing plants (e.g. dust, residual materials, expired prepregs, processing utilities, solvents, and additives. Production waste volumes in e.g Finland are appr. 1000-2000 tonne/year).
- End-of-life waste: generated when the product has reached its end-of-life time due to failure in structure or function or due to product replacement by design or consumer demands (long life time, inhomogeneous material composition, small volumes compared to other materials in the waste streams, difficult to estimate waste volumes).

Difficulties with the end-of-life composite recycling are that collecting, sorting and dismantling usually are practically difficult and expensive. Another obstacle is that there is no established market for the recycled composites today. There are a lot of small-scale examples of what to do with the recycled composite but there is a lack of demand to use the recycled composite in a new application.

Presented below are the recycling methods for composites, of which the first three are considered to have the highest potential:

- mechanical recycling by grinding
- energy recovery by incineration.
- a combination of energy recovery and material recycling
- chemical recycling.

Additional information about waste management treatment of some common composites are presented in Larsson [2004] in Appendix J.

Mechanical recycling
In mechanical recycling, the redundant composite product is ground into finer fractions, which then can be used as a filler or reinforcement in virgin composites. It is more economically feasible to use it as reinforcement than as a filler [Larsson, 2003]. The process requires collection, dismantling, sorting, cleaning, grinding, fractioning, and quality control in order to produce a reusable raw material. The resin must be fully cured to avoid the emissions of styrens, by occupational health and safety issues.

Collecting, dismantling, and sorting are necessary and expensive. Grinding techniques and the equipment needed is available today. Work has been going on in this area for 20 years [Larsson, 2003]. Technical possibilities and quality performance of the recycled material have been demonstrated, but economical feasibility has not. In order to receive useful recycled composite material, dismantling is preferred.

Energy recovery
By incineration it is possible to utilise the energy content of the material in energy production. Composite waste cannot be considered as one type of fuel for incineration, as the glass content, differences in heating values, combustion rates, and composition varies so much between different waste fractions. A high content of glass and filler in the material decreases the energy content (e.g. SMC) [Composit, 2004]. The energy contents of some composites are given in Table 5.11. Composites with lower glass contents or those reinforced with carbon or natural fibres can be incinerated in existing incinerators together with other fuels or wastes. The inorganic glass fibre reinforcement will remain in the residual ash. The energy content of an average GMT[16] composite, that gives 35 % ash content, is 2-3 times higher than municipal waste [Larsson, 2003].

Table 5.11. Energy content of different composites. The values have been developed in the Swedish VAMP 18-project aiming at giving guideline principles for recycling fibre composites.

Composite	Energy content [MJ/kg]	Comments
SMC, GMT	25-30	The energy content varies with glass content.
PP/flax	35-40	
CFRP	30	Both temperature and oxygen should be as high as possible and the material should be separated into small pieces in order to achieve complete combustion

Energy recovery combined with material recycling
The combination of energy recovery and material recycling is a recently developed concept that has potential. Here the composite is incinerated under controlled conditions, so that the glass fibre reinforcement can be collected. Carbon fibre composites can also be incinerated without destroying the carbon

[16] GMT: Glass Mat Reiforced Thermoplastic, is a thermoplastic matrix (e.g. PP, PA, PET) reinforced with orientated or random glass fibres of various length.

fibre reinforcement. This technique requires rather high volumes if glass fibre composites are processed, but with carbon fibre reinforced composites feasibility has already been achieved at low volumes. [Composit, 2004]

Chemical recycling
Chemical recycling of composites, which involves gasification, pyrolysis or hydrolysis of the polymer matrix, has in laboratory conditions been proven to be possible. However, it does not seem to be feasible in large scale.

5.6.2 Material market and flows of recycled material

Landfill and incineration have always been the simplest and preferred disposal methods for composites, accounting for 98 % of the waste. Only 2 % have been mechanically recycled or re-used. Landfill of composite waste will however be forbidden by the end of 2004 in most EU member states, and incineration will have limits imposed on the level of energy content. In addition, various EU directives (e.g. the ELV-directive) makes the producers demand that the composite industry provides a waste management concept that can fulfil the directives. This means that the composite industry now faces some major challenges. In order to meet these challenges, the key European suppliers, together with e.g. the European composite trade association and the GPRMC, are introducing a European Composite Recycling Concept. The participants will financially participate in the development of composite waste management solutions for end-of-life waste. Funding will be used to secure recycling opportunities, launch R&D programs to study new and improved ways of collecting and recycling composites, as well as seeking out and developing new markets for recyclate. [Harbers, 2003]

The biggest obstacle today to recycle composite components from transport applications is not the technical methods; it is instead the lack of end-use applications for the recycled composite. The price of raw material produced from recycled composites is considerably higher than the prices for virgin reinforcements and fillers. There also exists a scepticism regarding the quality and technical performance of the recycled reinforcement or filler, compared to virgin materials. Due to this, there is currently not really any market in automotive products where recycled composites are used. The situation is much the same in rail applications, although there should be better possibilities to introduce recycled raw materials, as the preferred processing techniques (vacuum injection, RTM) are not so raw material sensitive as in automotive applications. In aerospace it is not likely that recycled materials will be used due to the performance requirements. [Composite, 2004]

5.7 Rubber

More than 50 % of all rubber produced is used in tyre production (estimated 9 million tonnes of the total 17 million tonnes in 2000) [EU, 2002]. When tyres are produced, various grades of natural and synthetic rubber are combined with carbon black, sulphur and chemical products to meet specific compound requirements. In this study, only rubber in tyres is considered.

Most of the rubber used today in tyre manufacturing is petroleum based synthetic rubber. The most common rubber used in the production of automobile tyres is styrene-butadiene co-polymer (SBR). An average tyre for automobiles contain about 48 % of rubber, see Table 5.12.

Table 5.12. The material composition of tyres in the European Union. [ETA, 2004]

Material	Automobiles	Trucks/buses
Rubber /Elastomers[a]	48 %	43 %
Carbon black	22 %	21 %
Metal	15 %	27 %
Textile	5 %	-
Zinc oxide	1 %	2%
Sulphur	1 %	1%
Additives	8 %	6%

[a]Truck tyres contain more natural rubber compared to automobile tyres.

5.7.1 Recycling system and processes

The means of tyre disposal varies in each EU member state, but on average the means are landfill/stock (39 %), cement kilns (16 %), retreadability (12 %), export (11 %), size reduction (9 %), civil engineering (9 %) or other energy recovery (4 %). [EU, 2002]

In terms of environmental impact it can be argued that the extension of the useful life of the tyre is the most attractive form of recycling available, although market and safety factors influence the levels of tyre reuse.

Retreading, in which new tread material is applied to used carcasses, is a very important technology for increasing the usage of the majority of the tyre. Whilst retreading is an established approach for commercial (truck) tyres, only limited success has been attained in the passenger tyre market. From a recycling viewpoint it is concerning to note that the European retreading industry has been in steady decline over recent years and that there are no signs of recovery in sight. [EU, 2002]

Material recycling
Granulating is the basis for many operations of material recycling. It is often seen as an economical way to reduce the amount of rubber waste and allows the reuse of a wide variety of polymers. Recycled rubber can be in the form of crumb, surface activated crumb or reclaim, which can be used as a total or partial substitute for virgin compound. For example, finely ground tyre crumb is often added to tread compounds during the manufacture of new tyres, although usually only up to levels of 10 % if performance is to be retained. Standards are being drawn up for post-consumer tyre materials and applications to assist the commercial uptake of recycled rubbers.

By size reduction, mechanical fragmentation, the different material elements can be separated. It is possible to receive a wide range of grindings from shred and chips to fine powders. Each category is suited for different applications, e.g. thermal insulation, drainage, floor tiles, and automotive parts.

In order to receive recyclates with wide fields of application, it is recommended that the tyre feedstock is limited to either automobile or truck tyres. This is due to the differences in their structure and material content. The material content of each category is sufficiently similar to ensure that the resulting recyclates will contain consistent, identifiable characteristics and properties over time. This is however usually not economically feasible today.

In contrast to retreading, material recycling is enjoying ever increasing uptake into articles, such as brake linings, carpet backing, moulded products, playgrounds, road paving materials, shoe soles, sports fields, and porous drainage, where the crumbed material is often bound together with a suitable binder such as a urethane resin.

Energy recovery
Energy recovery (using tyre derived fuel) exploits the relatively high calorific value of the end-of-life tyre to fuel high energy processes. Such processes are e.g. electricity generation, cement kiln firing, and powering of pulp mills as well as providing the power for different forms of pyrolysis typically used for the extraction of the tyre base materials such as carbon black. Its ability to process large volumes of end-of-life tyres makes energy recovery a key component in all current co-ordinated approaches to tyre recycling and disposal. [EU, 2002]

5.7.2 Material market and flows of recycled material

Within EU, about 250 million tyres, equivalent to 2.5 million tonnes of rubber, annually reach their end-of-life. The historic tyre stockpiles are estimated to be in excess of 300 million tyres. [EU, 2002]

Indications show that the recycling capacity of post-consumer tyres will continue to expand. The recycling industry for tyres will be able to expand in order to accommodate a larger share of the increased quantities of tyres that will result from e.g. the implementation of the landfill directive within the European Union. According to this directive (1999/31/EC), whole used tyres are not accepted in a landfill from 2003, excluding tyres used as engineering material. In 2006 there is also a ban on land filling shredded used tyres. As mentioned above, 39 % of the tyres are land filled/stocked today, so the material market for used tyres are most likely to expand.

5.8 Polyurethane (PUR)

Urethane polymers (PUR) can be produced with a wide variety of properties, ranging from soft flexible foams to hard solids. Besides weight-savings and design freedom, polyurethanes are attractive to automobile designers because they offer advantages through increased comfort, corrosion resistance, insulation, and sound absorption.

PUR can be used in a diverse range of applications. The automotive industry provides a market for flexible foams, filling foams, rigid and flexible integral skin foams as well as elastomers for engineering components. Within the automotive industry, PUR is used for e.g.

- seat cushions and backs
- arm rests
- impact absorption in bumpers and dashboards
- sound-absorption (carpet linings, door-panels and headliners)

Other applications of PUR include coatings, adhesives, sealants, elastomers as well as fibres. The use of plastics and PUR in automobiles has increased during the last 15 years, and the amount of plastic material has almost doubled. The average automobile, weighting 1000 kg, contains today about 150 kg of plastics, of which 15 kg are various types of PUR parts. [Euro-Moulders, 2002]

5.8.1 Recycling system and processes

PUR is produced from the liquid basic materials polyhydric and isocyanate. After mixing the two components (under certain mixture ratios), a spontaneous increase in hardness or cross linking into the polymer form of PUR occurs. By adding various reagents, a variety of polyurethane foams with the most different qualities can be produced.

Polyurethanes can be recycled mechanically, chemically, and by feedstock recycling. Alternatively, their intrinsic energy value can be recovered by combustion.

Mechanical recycling
There are several methods for mechanical recycling processes currently in use as described below:

1. *Flexible foam bonding* represents the most important technology of mechanical recycling of PUR. The technology yields a variety of padding products, such as carpet underlay and athletic mats, from recovered pieces of flexible polyurethane foam. In 1999, 40,000 tonnes of padded products was produced from recycled PUR in Europe. More than half is dedicated to flooring applications. Another 60,000 tonnes are sent to the USA for carpet underlay. The market price level for baled PUR to be used for rebonded foam applications fluctuates very much when looking at historical figures, from 0.21 to 0.63 Euro/kg. [Mark and Kamprath, 2000]
2. *Regrind/Powdering*. Industrial and post-consumer flexible PUR foam is regrinded into powders for producing new foam. The use of pulverised PUR material as filler is another potential option from a commercial point of view. A 10 % loading with PUR powder in a new foam cushion seems to be technically viable. Loadings of 15 % might be possible in slabstock PUR foams, and such foams are used for mattresses and upholstered furniture, but also for rear automobile seats and fabric lining for seat covers and roofing in automobiles. Grinding economics vary as function of volumes produced and equipment used, from c.a. 0.34 to 0.63 Euro/kg. [Mark and Kamprath, 2000]

3. *Adhesive Pressing* coats polyurethane granules with a binder and then cures them under heat and pressure. Contoured parts, like automotive floor mats and tire covers, are made with this method.
4. *Compression Molding* produces rigid and 3-D parts, such as pump and motor housings, when polyurethane granules are molded under heat and pressure.

Chemical recycling

Several chemical recycling methods of PUR are available:

1. *Glycolysis* is the simplest chemical operation and results in different polyols depending on the type of PUR and of glycol used. Polyols is a key polyurethane raw material. In the glycolysis process, polyols are produced from process and post-consumer PUR scrap by reacting the scrap with diols at temperatures above 200 degrees Celsius. Glycolysis has since long been known as a method for chemical recycling of high-resistance foams and integral skin foams. This method is applied to e.g. the instrument panels of BMW. The polyol produced by glycolysis is only suitable to produce rigid PUR foams and is therefore not suitable for production of seats. The cost of the produced polyols are of similar prices as virgin materials ranging from 0.98 to 0.85 Euro/tonne. [Mark and Kamprath, 2000]
2. *Hydrolysis* is the reaction of PUR with water, and can produce both polyols and amine intermediates from PUR process and post-consumer scrap. When recovered, the polyols can be used as effective fuels, and the intermediates can be re-used to produce other polyurethane components. [API, 2004]
3. *Pyrolysis* uses a heated, oxygen-free environment to break down polyurethane and plastics into gas and oil. [API, 2004]
4. *Hydrogenation* takes pyrolysis one step further to produce even more pure gases and oils through a combination of heat, pressure and hydrogen. The purity of gases and oils derived from pyrolysis and hydrogenation, and the associated costs to produce functional finished products are important issues yet to be resolved.

Energy recovery

PUR foam has an energy content comparable to that of coal, resulting in about 25 MJ/kg [Strömberg and Ringström, 2003]. PUR foam contains insulation gas that might be flammable. When incinerating the foam, the gas still contained in the foam is destructed. It has been demonstrated that the emissions from modern MSW combustion plants are not increased by the presence of PUR foams.

5.8.2 Material market and flows of recycled material

Today, about 400,000 to 500,000 tonnes of PUR foam is recycled worldwide on a yearly basis. In Europe that figure is in the order of about 60,000 tonnes. This amount could be even higher if the necessary markets and applications would exist. [Euro-Moulders, 2002]

5.9 Comparison of materials

The value of a material is usually decided on the commodity market. When secondary material that is collected for recycling enters the commodity market, it competes both with primary material as well as other recycled material. The price of a material is affected by the demand and supply of the material. Some examples of prices of virgin materials are given in Figure 5.15.

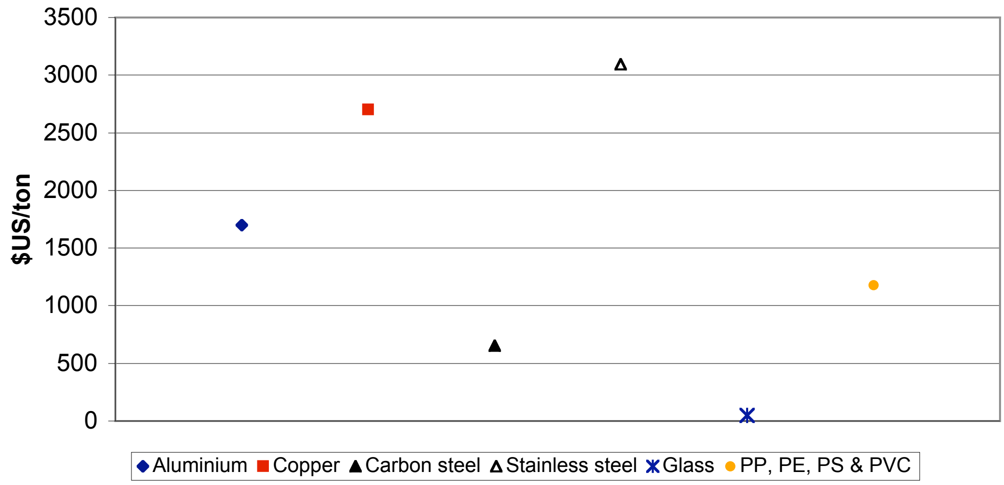


Figure 5.15. Prices of virgin material on the commodity market. Metal prices are from June 2004. Prices on glass and plastics are estimates.

When it comes to secondary material, not all materials have an economic value today. You may have to give the material away. Sometimes you even have to pay to get rid of the material, as for e.g. laminated glass. Examples of prices of secondary material are given in Figure 5.16.

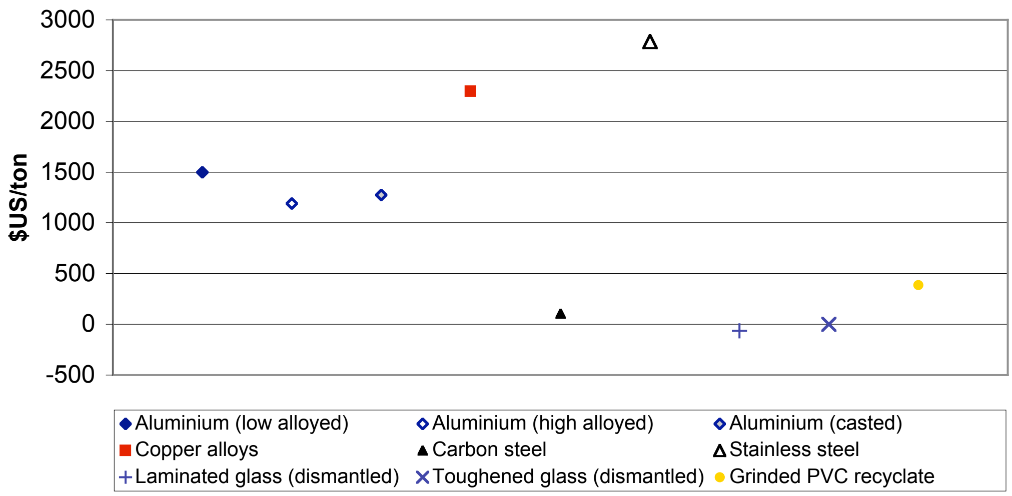


Figure 5.16. Prices of secondary material on the commodity market. Prices are based on recycling values (Al and Cu) as well as observed values on the market.

6 Scenarios of future recycling systems

The lifetime over several decades of vehicles, for example up to 20-30 years for an automobile, implies difficulties in integration of the ELV directive into the process of product development. The requirements of recyclability of the component materials of an automobile have to be taken into account before an automobile model is put in production. At the design stage of vehicles, uncertainties regarding the future recycling systems and related costs have to be considered. Moreover, the design of vehicles should enable a cost effective recycling, as well as include recycled materials in increasing extent to stimulate the further development of recycling processes and market.

There are different options to increase the recycling and recovery quotas compared to today, and hence different potential future recycling systems. Different recycling systems can imply different design guidelines for the vehicle industries.

In this section, four different scenarios for future recycling systems for end-of-life vehicles (automobiles) in Europe are presented for the years 2015 and 2030. A large part of the ELVs in 2015 are the automobiles that are manufactured today, and the ELVs in 2030 are the automobiles that are designed today. The year 2030 also represents a year when more comprehensive changes of the recycling system have had time to occur.

The scenarios are *no predictions* of the future recycling system but descriptions of *potential* recycling systems based on certain assumptions, such as technology development of recycling processes. The choice of scenarios is made to reflect a wide range of potential recycling systems. Manufacturing industries can choose to consider all potential scenarios, or to reject some scenarios. The recycling systems and material flows in the scenarios are based on assumptions about:

- choice of recycling processes, for example, dismantling versus shredding;
- technology development of recycling processes, i.e. which material fractions and the quality of these fractions.

There are two main strategies to fulfil the requirements of recovery and recycling quotas set up in the ELV directive, either to extend the dismantling of parts or to use some of the SR treatment technologies. As the dismantling is costly, the focus at the moment is on evaluating the available SR treatment technologies from economical, technical and, environmental point of views. We consider the strategy of an extended dismantling in one scenario and the strategy of an extended SR treatment in three scenarios, in different variations.

In the scenarios, we speculate about potential driving forces behind the change from today, for example, future laws or economic incentives.

The four scenarios are:

1. *Business as usual*, years 2015 and 2030, in which we assume a moderate technical development of recycling processes.
2. *Dismantling*, year 2030, in which we assume that several components will be dismantled for recycling before shredding.
3. *Best available technology*, year 2030, in which we assume a significant technical development of recycling processes, i.e. shredder processes and processes for pre-treatment of shredder residues.
4. *Energy recovery*, year 2030, in which we assume that a larger share of energy recovery is accepted compared to the present ELV directive.

6.1 Method

The material input used in the scenarios does not include fluids and materials dismantled at the pre-treatment of ELVs due to requirements in the Annex 1 of the ELV Directive, see Section 2. The material input to the recycling system in all scenarios is the material content of an average ELV of 1000 kg in the year of 2003, see Tables 6.1 and 6.2. Even though this is not a realistic development of automobile weight and material content over this time period, it fulfils the purpose to illustrate the influence of the recycling processes in the scenarios.

Table 6.1. Material content of an average ELV in the year of 2003 in Europe [Francois, 2003].

Materials	Weight (kg)
Metals, magnetic	705
Metals, non-magnetic	58
Rubber, in tires	35
Rubber, others	5
PUR foam	15
Mix PUR/textiles	62
Plastics	30
Wood	5
Glass, stones and gravel*	85
Sum	**1000**

* The fraction contains 45 kg glass. Stones and gravel are from the surroundings, both during usage of the vehicle and during the scrapping of the vehicle.

A material balance for a reference recycling system for the year 2003 is presented in Figure 6.1. These figures are based on facts and figures in Liljenroth [2004], in Appendix D.

INPUT → **SHREDDER (dry technology)** → **OUTPUT**

1000 kg ELV

↓

Dismantling and recycling

Recycling from shredder

- 700 kg magnetic fraction
- 50 kg non-magnetic

Sum: 750 kg

SR treatment/recycling

SR treatment/energy

Landfill

Plastics	30 kg
PUR foam	15 kg
Rubber	40 kg
Metals, magnetic	5 kg
Metals, non-magnetic	8 kg
Wood	5 kg
Mix PUR/textiles	62 kg
Stones, gravel, glass	85 kg
Sum	**250 kg**

Figure 6.1. A material balance for a reference recycling system for the year 2003.

Table 6.2. The share of plastics in an average automobile.

Plastic	**Share [%]**
ABS	17
ASA	1
PUR	17
PP	17
PP-EPDM	17
PVC	9
POM	2
PA	4
PMMA	1
PC	2
SMC	4
TPO	4
Polyester	4
Total	**100**

The estimated materials output in respective scenario is not a result of using one specific, well-defined, recovery process. Instead it is a mixture of processes that have a potential to be used in the future. In essence the result would reflect figures for an average European recovery. The assumptions made about the capabilities of future processes are based on descriptions of technology development of recycling processes in Liljenroth [2004] and Sjöberg [2003b], in Appendices D and E.

The assumptions on choice of recycling processes are based on the aim to reach recycling and recovery requirements at the lowest cost. However, some processes may not be profitable but may be paid through producer responsibility.

The quota between materials output and input in the scenarios cannot be used to calculate recovery levels (monitoring), since the material input does not include fluids and materials dismantled at the pre-treatment of ELVs.

6.2 Scenario 1: Business-as-usual

In this scenario, we assume a moderate technical and economic development of recycling processes, i.e., shredder processes and processes for pre-treatment of shredder residues. We assume that the current ELV directive is still valid. The material outflows estimated according to this scenario for the years 2015 and 2030 are presented in Figures 6.2 and 6.3.

The main strategy to increase the recycling and recovery quotas, and to substantially reduce the amount of materials sent for land filling is to introduce *SR treatment* and to separate plastics (including PUR) mainly for energy recovery but also for material recycling, see Table 6.3. The recycling quota is further increased by *dismantling* of tires and separation of glass at the SR treatment. It is uncertain to what extent the resulting materials fraction, mainly including minerals, will be demanded as a filling material or have to be sent for landfill.

INPUT

SHREDDER (dry technology)

OUTPUT

1000 kg ELV

Dismantling and recycling

- 35 kg tires

Sum: 35 kg

Recycling from shredder

- 702 kg magnetic fraction
- 53 kg non-magnetic

Sum: 755 kg

SR treatment/recycling

- 10 kg plastics
- 35 kg glass

Sum: 45 kg

SR treatment/energy

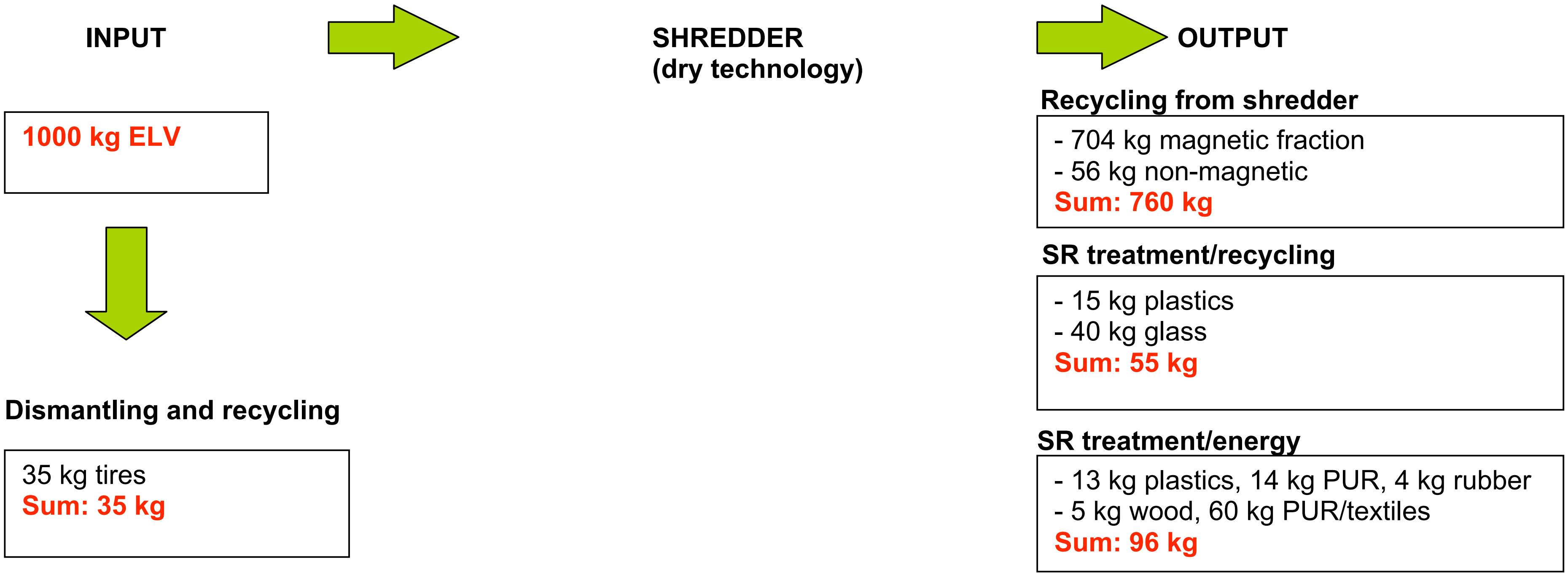
- 15 kg plastics, 12 kg PUR, 2 kg rubber
- 4 kg wood, 57 kg PUR/textiles

Sum: 90 kg

Landfill

Plastics	5 kg
PUR foam	3 kg
Rubber	3 kg
Metals, magnetic	3 kg
Metals, non-magnetic	5 kg
Wood	1 kg
Mix PUR/textiles	5 kg
Stones, gravel, glass	50 kg
Summa	**75 kg**

Figure 6.2. A material balance for Scenario 1, business-as-usual, for the year 2015.



Landfill/reuse as filling material

Plastics	2 kg
PUR foam	1 kg
Rubber	1 kg
Metals, magnetic	1 kg
Metals, non-magnetic	2 kg
Wood	0 kg
Mix PUR/textiles	2 kg
Stones, gravel, glass	45 kg
Sum	**54 kg**

Figure 6.3. A material balance for Scenario 1, business-as usual, for the year 2030.

Table 6.3. Amount of recycled and recovered materials of the material input, i.e. 1000 kg excluding materials dismantled and recovered at the pre-treatment of the ELVs. The interval depends on the amount of materials demanded as filling materials, alternatively sent for landfill.

Year	**2015**	**2030**
Material recycling	84 %	85-90 %
Material recovery	92 %	> 95 %

We assume that *tires* are dismantled before shredding and recycled or energy recovered. This is a change from today when tires are often landfilled after shredding (except in Sweden where tires are dismantled for recycling). The main reason is to fulfil the requirements in the ELV directive, and the treatment operations in order to promote recycling according to Annex 1.

The amount of *metals* separated for recycling is increased mainly by development of shredder technology but also by the build-up of SR treatment plants all over Europe (several plants in 2030 than in 2015). Only a minor amount of metals are left for landfill in the year 2030. The non-magnetic metals are separated into fractions of stainless steel, aluminium, magnesium, copper, and fine mixed materials that contain different alloys of copper-zinc, copper-tin, and zinc. The various metal fractions are subsequently sent for recycling. The metal fractions include fewer amounts of impurities compared to today but are still mixes of different alloys. There are economic incentives for an increased recycling of metals, mainly due to the value of the metals, but also due to decrease the amount of residues for landfill, and better quality of other material fractions such as the fuel fraction (i.e. less amount of metals in the fuel fraction).

Some *plastics*, for example, PP, PE, and ABS, are separated at the SR treatment and sent for mechanical recycling. Processes developed, for example, by Galoo and Salyp, can be used at the SR treatment. The plastics are separated before recycling. The recycled plastics has a lower quality than virgin plastics, and cannot be recycled more than a limited number of times, but can be used for some applications in automotives. The driving force for an increased material recycling of plastics is the requirement in the ELV directive.

Glass is also separated at the SR treatment, for example, in processes developed by Galoo and Salyp. The glass is either in a mixed fraction together with other minerals, which can be sent for recycling as a filling material in road constructions, or separated in a further process to a quality that can be demanded for other purposes, such as for glass wool production. The ELV directive is also here the main reason.

The SR treatment also results in *fuel fractions* (see for example the Galoo process), which can be sent for energy recovery, for example, MSW incineration or use in cement kiln, for a certain gate fee. The fuel fractions contain a less amount of impurities compared to untreated SR, i.e., less copper and other metals, and reduced chlorine content. An important incentive is to reach the recovery quota in the ELV directive. Other possible reasons are the prohibition to deposit burnable materials, as in Sweden today, or increased charges to put materials on landfill.

The resulting materials fraction contains mainly inert materials, and some metals and organic materials, see Table 6.4. The resulting materials are sent for landfill in the year 2015 and is either sent for landfill or for recycling as a filling material in the year 2030.

Table 6.4. The material content in the resulting materials fraction sent for landfill or for materials recycling as a filling material (only in 2030).

Materials	2015	2030
Inert materials	66 %	83 %
Metals	11 %	6 %
Organic materials	23 %	11 %

6.3 Scenario 2: Dismantling

In this scenario, we assume that several components will be dismantled for recycling before shredding. We assume that the current ELV directive is still valid. Material outflows estimated according to this scenario are presented in Figure 6.4.

The main strategy in this scenario to increase the recycling quota and to reduce the amount of materials sent for land filling is to increase the *dismantling* of materials for recycling, mainly tires, glass, and plastics (including PUR), see Table 6.5. The recovery quota is increased by the introduction of *SR treatment* and the separation of plastics and textiles into a fuel fraction. Similarly to Scenario 1, the extent of the resulting materials fraction, mainly including minerals, demanded as a filling material or have to be sent for landfill is uncertain.

Table 6.5. Amount of recycled and recovered materials of the material input, i.e. 1000 kg excluding materials dismantled and recovered at the pre-treatment of the ELVs. The interval depends on the amount of materials demanded as filling materials alternatively sent for landfill.

Year	2030
Material recycling	88-93 %
Material recovery	> 95 %

INPUT

1000 kg ELV

Dismantling and recycling

- 25 kg plastics
- 15 kg PUR
- 35 kg tires
- 40 kg glass

Sum: 115 kg

SHREDDER (dry technology)

OUTPUT

Recycling from shredder

- 704 kg magnetic fraction
- 56 kg non-magnetic

Sum: 760 kg

SR treatment/recycling

SR treatment/energy

- 3 kg plastics, 60 kg PUR/textiles
- 4 kg rubber, 5 kg wood

Sum: 72 kg

Landfill/reuse as filling material

Plastics	2 kg
PUR foam	0 kg
Rubber	1 kg
Metals, magnetic	1 kg
Metals, non-magnetic	2 kg
Wood	0 kg
Mix PUR/textiles	2 kg
Stones, gravel, glass	45 kg
Sum	**53 kg**

Figure 6.4. A material balance for Scenario 2, dismantling, for the year 2030.

As the main reason for an increased dismantling instead of shredding, we assume that the development of processes for SR treatment has not been successful. The processes are expensive and do not generate material fractions in the necessary quality demanded on the market. However, the dismantling process is still more expensive than the shredding alternative but this is no longer an issue since the material fractions out from the dismantling has a higher material quality and thus higher recycling value compared to the material fractions from shredding. We assume a significant development of technologies for dismantling, which implies less expensive processes and improved work conditions. We also assume that the society has realised the importance to preserve the material quality in the recycling of materials and there may be economic policy incentives that benefit the dismantling of materials for recycling.

Several components and materials, besides *tires*, are dismantled for recycling before shredding in this scenario compared to the reference year 2003. *Glass* is dismantled, as in Sweden today. The laminated glass in the windscreen and the toughened glass in the side and rear windows are sorted into separate bins and recycled separately, which increase the quality and possible applications for the recycled glass. The main reason for this recycling is to reach the recycling criteria in the ELV directive. A few components of *valuable metals* are dismantled of economic reasons, such as stainless steel, aluminium, and copper.

Large components made of common *plastics*, i.e. PE or PP, and smaller components made of more valuable plastics, such as PA, ABS, PC/ABS, and PMMA, are dismantled and recycled mechanically. The sorting into separate bins increases the quality and demand (at this stage), and reduces the costs for the following recycling processes. However, the quality and demand of the recycled plastics are lower than compared to virgin plastics. Components of PUR (mainly seats) are also dismantled for recycling. The total material recycling of plastics (not as filling materials) is four times higher in this scenario than in Scenario 1. The main reason for the recycling is to fulfil the requirements on recycling in the ELV directive. Moreover, additional requirements on recycling of specific plastics as a complement to the ELV directive can be assumed as another reason.

There is a *fuel fraction* for energy recovery out from the SR treatment. The incentive is to reach the recovery criteria in the ELV directive. The remaining material residues mainly include *stones and gravel* and can either be sent to landfill or for material recycling as filling material.

6.4 Scenario 3: Best available technology

In this scenario, we assume a significant technical development of recycling processes, i.e., shredder processes and processes for pre-treatment of shredder residues. There has been significant development of technologies to sort and recycle materials from SR. The material fractions from the pre-treatment of shredder residues achieve higher material quality and thus higher recycling values compared to today. We present estimated material outflows in Figure 6.5.

INPUT

SHREDDER
(dry technology)

OUTPUT

1000 kg ELV

Dismantling and recycling

Recycling from shredder

- 704 kg magnetic fraction
- 56 kg non-magnetic

Sum: 760 kg

SR treatment/recycling

- 20 kg plastics
- 15 kg PUR foam
- 35 kg tires, 45 kg glass

Sum: 115 kg

SR treatment/energy

- 10 kg plastics, 5 kg rubber
- 5 kg wood, 62 kg PUR/textiles

Sum: 82 kg

Reuse as filling material

Plastics	0 kg
PUR foam	0 kg
Rubber	0 kg
Metals, magnetic	1 kg
Metals, non-magnetic	2 kg
Wood	0 kg
Mix PUR/textiles	0 kg
Stones, gravel, glass	40 kg
Sum	**43 kg**

Figure 6.5. A material balance for Scenario 3, best available technology, for the year 2030.

The main strategy in this scenario to increase the recycling and recovery quotas is to introduce an advanced technology for *SR treatment*. Driving forces for this development can be higher landfill cost, higher cost for incineration, taxes on virgin materials, or specific recycling requirements on plastics (see Section 2 on future trends for laws related to recycling).

Table 6.6. Amount of recycled and recovered materials of the material input, i.e. 1000 kg excluding materials dismantled and recovered at the pre-treatment of the ELVs. The interval depends on the amount of materials demanded as filling materials alternatively sent for landfill.

Year	**2030**
Material recycling	88-92 %
Material recovery	> 96 %

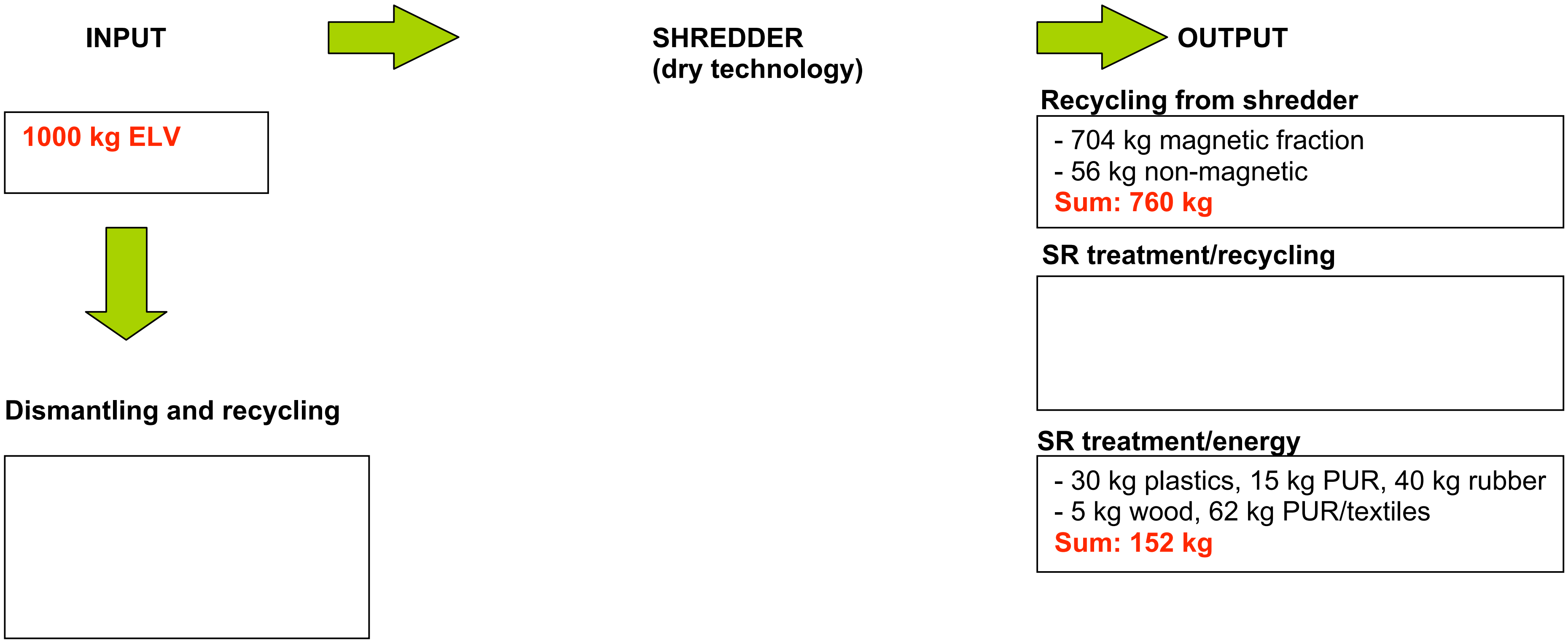
In this scenario, no components (except in the pre-treatment) are dismantled. Several materials fractions are separated at the SR treatment and sent for either material recycling or for energy recovery. All *thermoplastics* are separated at the SR treatment. Advances technologies are used for the separation into different types of plastics, which are either mechanically or chemically recycled. Chemical recycling can result in the same material qualities and demand as for virgin materials. *Rubber from tires* is separated into one fraction and recycled to simpler components of rubber. *Glass* is also separated at the SR treatment into a separate fraction and used for simpler applications.

The demand of the resulting *mineral* fraction as a filling material is increased by its improved quality.

6.5 Scenario 4: Energy recovery

In this scenario, we assume that a larger share of energy recovery is accepted compared to in the present ELV directive. We present estimated material outflows in Figure 6.6.

There can be several reasons for this change of acceptance. The main reason can be that the society wants to increase the reduction of green house gas emissions and therefore encourage a reduction of fuel consumption in automobiles, for example, by an increased use of lightweight materials such as plastics and composites. The present ELV directive does not encourage the use of plastics and composites in the automotive industry since the recycling of these materials can be difficult and expensive. This can be combined with the reason that the development of technologies for SR treatment can have been less successful, which results in expensive materials with qualities not fulfilling the demands on the market (with focus on plastics).



Reuse as filling material

Plastics	0 kg
PUR foam	0 kg
Rubber	0 kg
Metals, magnetic	1 kg
Metals, non-magnetic	2 kg
Wood	0 kg
Mix PUR/textiles	0 kg
Stones, gravel, glass	85 kg
Sum	**88 kg**

Figure 6.6. A material balance for Scenario 4, energy recovery, for the year 2030.

The main strategy to increase the recovery quota in this scenario is to introduce *SR treatment*, and to separate a large fuel fraction for energy recovery including the main part of the organic materials in the vehicle, i.e., plastics, PUR, and rubber (mainly from tires), see Table 6.7. Glass, together with stones and gravel, is included in the resulting inert material fraction, which can be used as a filling material. In this scenario, no components (except in the pre-treatment) are dismantled.

Table 6.7. Amount of recycled and recovered materials of the material input, i.e. 1000 kg excluding materials dismantled and recovered at the pre-treatment of the ELVs. The interval depends on the amount of materials demanded as filling materials, alternatively sent for landfill.

Year	**2030**
Material recycling	76-85 %
Material recovery	> 91 %

6.6 Recycling and recovery quotas in future recycling systems

The figures presented in this Section only give a hint of the recycling and recovery potential in the different scenarios. One reason is that fluids and materials dismantled at the pre-treatment of ELVs are not included. Another complication when calculating the recycling and recovery quotas is the question of which processes and applications that are accepted as material recycling or energy recovery, see Section 2. It is also difficult to make an assumption of to what extent the resulting materials fraction, mainly including minerals, will be demanded as a filling material or have to be sent for landfill.

The material content in future automobiles will change due to other reasons than to design for recycling, such as a reduction of fuel use. This change of material content will affect the potential recycling and recovery quotas. For example, the ferrous metal content in vehicles has been continuously reduced over the last years due to an increased content of plastics. Using a standard shredder process and only recycle the metals fractions consequently implies a decreased recycling quota. Therefore, it is necessary to recycle additional materials than metals to increase or keep the material recovery constant as compensation to the ferrous recycling decrease.

During a full size experiment of ELV treatment of 201 automobiles with the Shredder Residues Treatment Line (SRTL) developed by Galoo, the material recycling reached 77 % and the total recovery reached 84.5 % (85 %, including recovery of the fluids and the battery) [Francois, 2003; APME/EUCAR, 2003], see Table 6.8. The full size experiment was conducted by PSA (Peugeot Citroën SA) and Renault together with Galoo during the winter of 2002. PSA and Renault calculated the material composition of the 201 shredded vehicles, in order to set a mass balance of the trial (inlet versus outlet). All ELVs shredded were "complete" (i.e. no components were removed for re-use) and they were depolluted (drained from fluids, removal of battery etc.) according to Belgium environmental requirements. The SRTL process implies additional metal recycling and energy recovery (RDF) in cement kiln. The trial included the polyolefin sorting step (PP and PE) as well as a polystyrenes sorting step. The recovery rate includes the operation of the Galloo-Plastics plant and additional recovery gained by the Galloo official ELV depollution centres. The shredding and the post-shredding processes recover 98 % of the metal content (ferrous and non-ferrous) and 50 % of the total PP and PE content of the automobiles.

Table 6.8. Specific recycling and recovery rates for different material and energy fractions (% weight) for the full size experiment of ELV treatment with the Shredder Residues Treatment Line (SRTL) developed by Galoo [Francois, 2003; APME/EUCAR, 2003].

Ferrous metal	Non-ferrous metal	Plastics: PP+PE and polystyrenes	**Material recycling**	RDF	Tires	**Total recovery**	Landfill	**Total**
68.18	5.43	3.39	**77**	4.00	3.47	**84.5**	15.53	**100**

6.7 Future recycling systems for trucks and rail vehicles

The general differences of future recycling systems for trucks and rail vehicles compared to automobiles are not significant. Automobiles represent the major part of the waste fraction from the whole automotive industry, including trucks and rail vehicles, which affects the material technologies and legal waste strategies that consequently are developed to suit to the automobile industry. Furthermore, the component materials of trucks and rail vehicles are similar to automobiles, though the amounts vary. Therefore, it is reasonable to assume that the waste strategies developed for automobiles will be applicable also for the smaller waste fractions of trucks and rail vehicles.

Generally, the trucks are designed for 1,000,000-1,250,000 km. Thus the life cycle of a truck (in years) varies with the average distance the truck is in use during a year (in km/year), which implies that the length of life of a truck can be significantly shorter than the life cycle of an automobile. A life length of 10 years is not unusual.

Trucks are attractive for the market even after their registration off road, since its various components are demanded as spare parts. The material in the various components may still be of a sufficient quality for further use though the truck cannot be used for its purpose as entity. Therefore, dismantling of parts and their consequent reuse may be more relevant end-of-life treatment of trucks compared to automobiles. However, the general trend in the design of trucks is that the various parts and components became more complex and fewer, which may reduce the amount of spare parts on the market.

The material content in future vehicles will change due to other reasons than to design for recycling, such as a reduction of fuel and energy use. Trucks consist approximately of 83 % of metals, 6 % of plastics, and the rest 11 % of other materials [Klintbom and Wahlström, 2001]. However, the high amounts of metals are, similarly to product development in the automobile industry, continuously reduced and replaced by various plastics and their composites, aluminium, magnesium, and thin sheet iron, mainly because of their low weight.

The change of material content will affect the potential recycling and recovery quotas. There has been a reduction in the ferrous metal content in vehicles over the last years due to an increased content of plastics. This development will continue. Using a standard shredder process and only recycle the metals fractions will imply a decreased recycling quota. It is necessary to recycle additional materials than metals to increase or keep the material recovery constant as compensation to the ferrous recycling decrease. To make the recycling activities increase for other materials than metals, the demand to use recycled materials in new production must increase.

A typical operating distance for a regional train is 230,000 km/year. They are often designed for a service life of 30 years but in practice the lifetime often is longer; 30-50 years. Rail vehicles are normally built in a modularised design so that overhaul, maintenance, component reuse and refurbishment are facilitated. This is expected to increase in future and this will imply that disassembly at end-of-life gets easier. The design for disassembly is however limited by the vandalism aspect; it should not be too tempting and too easy to brake down the vehicle in pieces during operation.

A regional train consists approximately of 82 % metals, 4 % plastics, and the rest 14 % of other materials [Larsson, 2004]. The trend to strive after weight reduction will continue, especially for rail vehicles that accelerate a lot, such as metros and regional trains. For high speed trains the front design and aerodynamic drag is of more importance to minimise the energy use. Locomotives need to maintain a high weight to achieve good traction properties.

An extension of the producer responsibility to encompass larger vehicles is not planned at the moment [Miljödepartementet, 2001; DG Environment, 2004], see Section 2.3 on future trends.

7 Design guidelines for recycling

There is today several design for environment guidelines available, within the manufacturing industries, which can be considered by designers at the product development. A large part of them promote recycling. There are several motives for design for recycling within the automotive industry, for example:

- laws and regulations, such as the recycling and recovery requirements in the ELV directive,
- environmental, health, or sustainability reasons, and
- economic reasons, such as a reduced cost for recycling or an increased demand of recycled materials.

Design guidelines are developed and suggested by researchers, manufacturing industries, and recycling industries, which may have different motives for design for recycling. Different guidelines have also been developed at different times under different conditions and based on different knowledge, for example, concerning technology development of recycling processes and market of recycled materials.

A main obstacle for design for recycling is when there is a contradiction between the guidelines for recycling and other aspects that has to be considered for at the product development such as market, economy, design, production, and other environmental issues. The designers have to make evaluations and priority selections of different aspects. Another obstacle is that the economic benefits of design for recycling are not explicit in the guidelines and not included in the total economic analysis of the product. There is also a lack of knowledge about the relevance of different guidelines depending on uncertainties about the future recycling system and market.

In the design practice, the use of design guidelines for recycling can be facilitated and increased if their motives and relevance are made clearer and, when possible, the economic benefits are made explicit.

Design guidelines can (based on different motives) focus on different aspects of recycling, for example:

- *to increase the recycling or recovery quota* (for example, due to the ELV directive): for example, by choosing materials that are easily recyclable;
- *to facilitate pre-treatment or dismantling* (for example, to reduce costs): for example, by using few joining elements and promoting easy identification of parts;
- *to increase the quality of recycled materials*(for example, to increase the demand of recycled materials): for example, by avoiding hazardous substances and using recycled materials in their own manufacturing.

7.1 Design guidelines based on scenarios

In this section, we suggest relevant design guidelines for recycling based on the four scenarios of future recycling systems for ELVs in Europe, presented in Section 6. The scenarios result in different sets of design guidelines for recycling. Thus, different sets of design guidelines are relevant depending on which recycling system will be in use when the automobiles that are developed today will be at their end of life. While some design guidelines are relevant for all scenarios, others are only relevant for a certain future recycling system.

It is relevant for designers to be aware of the relevance of different design guidelines. Manufacturing industries can choose to consider all potential scenarios, or to rank the scenarios, according to most realistic or most wanted, and aim at a certain scenario (proposed in this report or by themselves). Choosing one or several scenarios narrows the number of relevant design guidelines for recycling to consider. The product development gets relevant input and project resources are efficiently used.

The suggested design guidelines are also based on different *aspects of recycling*, which are based on different motives. Explicit motives for the guidelines can facilitate the priority of different guidelines. For example, guidelines aiming at a certain aspect, such as an increased recycling quota, may be prioritized.

7.1.1 Common for all scenarios

The *recycling quota* can be increased if materials that can be and are recycled are chosen. Common for all scenarios is that *metals* are easy and economical beneficial to recycle and that a large fraction of metals implies a large recyclability. However, composites should be avoided.

The *recovery quota* can further be increased if materials that can be and are used as a fuel are chosen. Polymeric composites including vegetal fibres should be used instead of other composites.

Pre-treatment and dismantling can be facilitated if components and materials relevant to be dismantled are *designed for disassembly*. However, the materials relevant to dismantle varies in the different scenarios, see below. There is a large amount of experiences and research on how to design vehicles and components to facilitate disassembly and to reduce the time for disassembling, see for example [Forss and Terselius, 1994; Bröte, 1998; Kondo *et al.*, 2000; Franzén, 2001]. We will not go into the details of this in this report.

Pre-treatment and dismantling can also be facilitated if components and materials to be dismantled are *labelled* to be easily identified and sorted. A harmonised and standardised system for labelling and removal of *hazardous substances* would be very beneficial and more cost efficient. Today, there exist no harmonized and standardized "language" /system for identifying and disassembling components containing hazardous or disturbing substances. Most of disassembly and recycling is based on the current knowledge in the brains of the scrapper, if you do not have access to a manual. This means that the degree of recycling varies widely from country to country, and even between different scrapping plants within a country.

The *quality* and demand of material and fuel fractions from shredding and from SR treatment are increased if *hazardous substances* are either avoided at the design of products or removed at the pre-treatment or dismantling, and thus are labelled and designed for disassembly. This is also valid for chlorine-containing materials, such as PVC, and for copper. Avoid the use of PVC and copper, for example, in electrical cables, since these are usually not dismantled, and use other less hazardous and problematic materials instead, for example, aluminium or fibre optics.

The demand and value of *metals* can be increased if the *quality* is increased, for example, less copper in the magnetic fraction and less iron in the aluminium fraction. Metals are separated for recycling from shredding in all the scenarios (besides some valuable metals in the scenario for dismantling). Shredding is assumed to play a central part since it is the most preferred and economical recycling method today. Therefore, metal components should be joined to easily separate at the shredding. For example, EU DG XII supported work has started to imaging solutions for separating larger quantities of copper from electrical motors via the "crushable core electrical motor" design for recycling route.

7.1.2 Scenario 1: Business as usual

The *recycling quota* can be increased if materials that are recycled are chosen. Plastics that are recycled in this scenario are common thermoplastics such as PP, PE, and ABS.

The *recycling quota* can also be increased if the separation of recycled *plastics* is increased from the SR treatment. Processes used for the separation are usually based on the density of plastics. Thus, densities of different plastics should, if possible, differ and the densities of one type of plastic should stay within a certain interval. The joining of components also affects the separability.

The *recovery quota* can further be increased if the recovery of *organic materials* is increased from the SR treatment. Choose materials and design the product to easily separate plastics, PUR, rubber, wood, and textiles from other materials. The separability depends on the joining of components and on the densities of the materials.

The *demand* of the *glass* fraction from the SR treatment can be increased if the *quality* is increased. The quality is increased if the material composition is known and stable. For example, choose the same material content in screen prints in all brands.

The *demand* of the *plastic* fraction from the SR treatment can be increased if the quality is increased. For example, it can be advisable to use PP with a sufficient amount of antioxidant to last throughout more than one life cycle, since antioxidants added to an already degraded material do not prolong the service life of the material [Jansson, 2000]. Anti-corrosion coatings should be avoided for

HDPE, since they can contaminate the polymer and act as stress concentrators in the recycled polymer.

7.1.3 Scenario 2: Dismantling

The *recycling quota* can be increased if the *dismantling of plastics* can be increased. Choose few types of plastic. Choose common plastics in large components (PE, PP, ABS) and otherwise valuable plastics, such as PA, ABS, PC/ABS, and PMMA.

The *recycling quota* can be increased if the *dismantling of glass* can be increased. For example, built-in threads in windows can facilitate dismantling but may increase the risk of car theft.

The *recovery quota* can further be increased if the recovery of *organic materials* is increased from the SR treatment (as in Scenario 1). Choose materials and design the product to easily separate plastics, PUR, rubber, wood, and textiles from other materials. The separability depends on the joining of components and on the densities of the materials.

The *demand and quality* of metals is increased for *valuable metals* that are dismantled. Choose valuable metals, such as stainless steel, aluminium, and copper, and design components of valuable metals for disassembly.

7.1.4 Scenario 3: Best available technology

In this scenario, it is assumed that no detailed design guidelines for recycling are needed since the techniques for SR treatment will be adjusted after how the products changes with regard to material content, resulting in cleaner fractions and a higher portion of material recycling.

However, the *recycling quota* can be increased if more *organic materials* (i.e. plastics, PUR, rubber, wood, and textiles) are recycled instead of energy recovered. The main design guideline is to choose materials that can be and are material recycled.

7.1.5 Scenario 4: Energy recovery

The *recovery quota* can be increased if the recovery of *organic materials* is increased from the SR treatment (as in Scenarios 1 and 2). Choose materials and design the product to easily separate plastics, PUR, rubber, wood, and textiles from other materials. The separability depends on the joining of components and on the densities of the materials.

7.2 Analysis of existing design guidelines based on scenarios

In this Section, we analyse a selection of existing design guidelines published by Volvo Truck Corporation, see Table 7.1, and summarized by Bombardier

Transportation, see Table 7.2. We have added comments to the guidelines and relevance according to the four scenarios of future recycling systems. (The comments may not reflect the original motive of the specific guideline.)

We have analysed the selection of existing guidelines och looked for examples of guidelines that may be rejected, should be complemented with information, and are missing.

Some reasons for *rejecting* guidelines can be that they may not be relevant for any future recycling systems or may be relevant only for some future recycling system that may be rejected. For example, it may never be relevant to:

- "Design [whole] products [vehicles] that require the shortest possible dismantling time".

If a manufacturing company choose to reject a scenario for future recycling systems, for example, a "dismantling scenario", they can reject some guidelines, for example:

- "Design products so that it is possible to dismantle high-value metals".

Guidelines, as they stand alone, often need some *complementary information* to be useful for designers. (In many cases, there is information available, but we have not examined when this is the case.) The complementary information should be based on conditions in potential future recycling systems. Examples of guidelines that should be complemented with information on *which materials are recyclable or compatible with each other* are:

- "Select recyclable materials",
- "Use glue, tape, labels and use surface materials that are compatible with underlying material".

A specification of *which materials and components should be designed for disassembly* should be added to some guidelines, for example:

- "Use as few joining elements as possible and use structures that allow non-destructive disassembly".

Specified information on *how materials and components should be joined to facilitate separation at shredding* should be added to guidelines such as:

- "Different metals should be joined together in a way that ensures that they can be subsequently recycled as high-value alloy"
- "Make sure that metals can be separated from other materials"
- "Facilitate the separation of materials in the shredder process by choosing a simple design, few different materials, and a low grade of mixing the different materials"
- "Avoid combining steel with copper, tin, bismuth, and lead"

Guidelines that are missing can include:

- choice of plastics (based on their densities) to facilitate separation at SR treatment;
- choice of metal alloys to increase the quality and demand of recycled metals, for example, avoid rare alloying elements that can reduce the quality of other alloys.

Table 7.1. A selection of design guidelines based on the report "Environmental guidelines for product development" published by Volvo Truck Corporation [Volvo Truck Corporation, 1997]. We have added comments to the guidelines and relevance according to the four scenarios of future recycling systems in Section 7: 1) business-as-usual, 2) dismantling, 3) best available technology, and 4) energy recovery. "x" indicates a high relevancy and "-" a low or no relevancy for a specific scenario.

A) Choice of materials		**Scenarios**			
Design guidelines	**Comments**	**1**	**2**	**3**	**4**
Avoid the use of materials containing *harmful substances*. Harmful materials have a high processing costs and may pollute materials that otherwise could be recycled. The harmful materials impair the possibility for energy recovery, since they occurrence implies risk to exceed the energy recovery facility‘s emission limits.	Increase the quality of recycled materials	x	x	x	x
Select recyclable materials.	Increase the recycling quota	x	x	-	-
Use *recycled materials* if possible. To stimulate the improvement and development of the recycling system, a sustained demand for the recycled materials and products should be established.	Increase demand of recycled materials	x	x	x	x
Polymer materials:					
Thermoplastics are preferable to use, especially polyethylene (PE) and polypropylene (PP). A complete incineration process leads to formation of water and carbon dioxide, without any additional emissions.	Increase the recycling quota (of polymer materials) Increase the quality of recycled materials	x	-	-	x
Avoid the use of *PVC*. In the production of PVC, additives are used, which are either hazardous or suspected of being hazardous.	Increase the quality of recycled and recovered materials	x	x	x	x
Thermoset plastics are preferable to use than metals due to their low weight, which consequently leads to reduced fuel use. However, thermoset plastics are difficult to recycle.	Affects the recycling quota	x	x	-	-
Fabrics and leather:					
Fabrics should meet Öko-Tex standard 100 (see www. medsols.se/klassificeringegen.html).		x	x	-	x
Avoid the use of *flame retardant agents* that contain bromine or chlorine.	Increase the quality of recycled and recovered materials	x	x	x	x
Use *leather* that is tanned by a more environmentally suitable method than by chromium based method, since chromium and its compounds are classified as environmentally hazardous substances.	Increase the quality of recycled and recovered materials	x	x	x	x
Surface treatment:					
Avoid unnecessary *surface treatment*. For example, colour impregnation of plastics may be a better alternative than surface painting.	Increase the quality of recycled materials	x	x	-	x

Table 7.1. (cont.)

A) Choice of materials (cont.)		**Scenarios**			
Design guidelines	**Comments**	**1**	**2**	**3**	**4**
Metals:					
Use high-tensile steel, aluminium, or magnesium. The reduced weight of a vehicle leads to reduction of fuel used. In addition, metals are, generally, easy to recycle.	Increase the recycling quota	x	x	-	-
Mercury, cadmium, hexavalent chromium, and lead, known as hazardous materials, should not be used either by themselves or in compounds.	Increase the quality of recycled materials	x	x	x	x
Different *metals* should be joined together in a way that ensures that they can be subsequently recycled as high-value alloy.	Increase the quality of recycled materials	x	x	-	-
Chemicals					
Substances on Volvo's black list, STD 100-0002 [Volvo Group, 2003] are not to be used in production.	Increase the quality of recycled materials	x	x	x	x
Substances on Volvo's grey list, STD 100-0003 [Volvo Group, 2004b], ought not to be used in production.	Increase the quality of recycled materials	x	x	x	x
Use the *Volvo's white list*, STD 100-0004 [Volvo Group, 2002], which contains suggestions for alternative substances.	Increase the quality of recycled materials	x	x	x	x
Adhesives:					
If possible, avoid the use of *adhesives*, since they can impair the potential for recycling.	Increase the quality of recycled materials	x	x	-	x
If it is essential, use, in order of precedence, hot-melt adhesive, contact glue, or two-component hardening adhesive (such as epoxy glue or PUR).	Increase the quality of recycled materials	x	x	-	x
***Glass*:**					
If possible, the *glass* used should be a simple glass without any additional materials.	Increase the quality of recycled materials	x	x	-	x
B) Engineer for recycling		**Scenarios**			
Design guidelines	**Comments**	**1**	**2**	**3**	**4**
Design products that require the shortest possible dismantling time. The easier the dismantling process, the better the economy of the recycling, which consequently lead to increased interest for recycling.	Facilitate dismantling for recycling	-	x	-	-
Design products so that it is possible to dismantle *high-value metals* (particularly copper, aluminium, and magnesium – prior to shredding)	Facilitate dismantling for recycling Increase the quality of recycled materials	-	x	-	-
Glass components should be easy to dismantle.	Facilitate dismantling for recycling	x	x	-	x

Table 7.1. (cont.)

B) Engineer for recycling		Scenarios			
Design guidelines	**Comments**	**1**	**2**	**3**	**4**
Simplify the removal and dismantling of *dangerous waste*: - For fluids and materials that must be recycled or processed according to law there must be safe ways to handle such products. - Nipples for drainage of fluids - Containers with a well-marked lowest point - Marking for holes if drainage nipples are not fitted - Hazardous waste (batteries, lead, wheel-balancing weights, fluids, airbag systems, electronic units etc.) should be conveniently accessible and designed for ease of removal and dismantling.	Facilitate pre-treatment	x	x	x	x
Minimise the use of various materials if possible. Design for ability to sort different materials.	Facilitate dismantling for recycling Increase the quality of recycled materials	x	x	-	x
To facilitate the identification of the type of the *plastics* used, all plastic components should be marked according to the Volvo standard, STD 103-002, Generic identification and marking of plastics products [Volvo Group, 2004a].	Facilitate dismantling for recycling Increase the quality of recycled materials	-	x	-	-
Avoid unnecessary *surface treatment*. Surface material should be compatible with the underlying material.	Increase the quality of recycled materials	x	x	-	x
Avoid the use of *adhesives* if possible.	Increase the quality of recycled materials	x	x	-	x
Use *glue, tape, labels* that are compatible with underlying material.	Increase the quality of recycled materials	x	x	-	x

Table 7.2. A summary of guidelines related to Design for Recycling made by Bombardier Transportation. References are DfE guidelines [Lagerstedt, 2004] and guidelines compiled by Stena Metall [Domini, 200X]. We have added comments to the guidelines and relevance according to the four scenarios of future recycling systems: 1) business-as-usual, 2) dismantling, 3) best available technology, and 4) energy recovery. "x" indicates a high relevancy and "-" a low or no relevancy for a specific scenario

Design guidelines	Comments	Scenarios			
		1	**2**	**3**	**4**
Promote upgrading, repair, and recycling by using *few, simple*, and *recycled materials*.	Increase the recycling quota (facilitate dismantling and shredding) Increase the demand of recycled materials	x	x	x	x
Do not use prohibited and restricted substances in the construction according to Bombardier Transportation Prohibited and Restricted Substances GRP-20-20-15-000014.	Increase the quality of recycled materials Reduce pre-treatment	x	x	x	x
If a hazardous substance cannot be substituted, consider if closed loops can be arranged, i.e., design for a simple dismantling so that the component can be taken care of at end-of-life, and the different materials recycled.	Facilitate pre-treatment	x	x	x	x
Promote easy identification of parts containing hazardous substances, e.g., by labelling or marking.	Facilitate pre-treatment	x	x	x	x
Promote easy identification of parts that will be recycled, e.g., by labelling or marking. Mark polymers according to ISO 11469 including the appropriate symbol in the mould design, by embossing, by melt imprinting or by other legible and indelible marking of the polymer.	Facilitate dismantling for recycling	-	x	-	-
Maximize the fraction/degree of metals used (most valuable are noble metals, copper, stainless steel, aluminium, steel in this order) and make sure that the metals can be separated from the other materials.	Able to separate either at dismantling or shredding Increase the recycling quota	x	x	-	-
Copper needs to be able to separate from other materials and metals.	Able to separate at either dismantling or shredding? Increase the quality of recycled materials	x	x	x	x
Facilitate the separation of materials in the shredder process by choosing a simple design, few different materials, and a low grade of mixing the different materials.	Increase the recycling quota Increase the quality of recycled materials	x	x	x	x
Minimize the amount of composite materials used. From a recyclability point of view, sandwich constructions and laminate materials are preferable rather than glass fibre reinforced polymers.	Increase the recycling quota	x	-	-	-

Table 7.2. (cont.)

Design guidelines (cont.)	Comments	Scenarios 1	2	3	4
Minimize the amount of composite materials used. From a recyclability point of view, it is easier to recycle glass fibre reinforced polymer sandwiches if they are dismantled, not shredded.	Increase the recycling quota	-	x	-	-
Avoid combining *steel* with copper, tin, bismuth, and lead in such way that the steel fraction gets contaminated with these substances.	Increase the quality of recycled materials	x	x	x	x
Avoid combining *aluminium* with copper, zinc, nickel, magnesium, and iron in such way that the aluminium fraction gets contaminated with these substances.	Increase the quality of recycled materials	x	x	x	x
Avoid combining *copper* with iron, stainless steel, antimony, and bismuth in such way that the copper fraction gets contaminated with these substances.	Increase the quality of recycled materials	x	x	x	x
Select recyclable *polymers* (or the most recyclable). - Select homogeneous polymers, e.g., avoid composites and laminates containing metals and ceramics. - Select thermoplastics rather than thermosets. - Select thermoelastomers rather than (vulcanised) rubbers.	Increase the recycling quota	x	x	-	-
Design the component such that the polymer detail doesn't exposes to UV-radiation, contamination and temperature changes, which might affect the properties of polymer and its recyclability.	Increase the recycling quota	x	x	-	-
Use a modularized design.	Facilitate dismantling	-	x	-	-
Use as few joining elements as possible and use structures that allow non-destructive disassembly. Reduce the number of fasteners and separation points.	Facilitate dismantling	-	x	-	-
Use the product form and markers to facilitate disassembly.	Facilitate dismantling	-	x	-	-
Keep polymers "clean", e.g. avoid painting, gluing, stickers and polymers containing additives.	Increase the quality of recycled materials	x	x	-	-
Use standard metal alloys to facilitate economic recyclability.	Increase the demand of recycled materials	-	x	-	-
Avoid using halogenated polymers (i.e. containing F, Cl, Br, I, or At) such as PVC.	Increase the quality of recycled materials	x	x	x	x
Use natural fibres e.g. wood and flax in polymer composites rather than glass fibres.	Increase the recovery quota	-	-	-	x

7.3 Economic optimisation of dismantling in the recycling system

A method for economic optimisation of dismantling in a recycling system has been developed in this project, and is presented in Forsberg [2004] in Appendix L. The question posed is what parts to manually dismantle before the rest is sent to shredding to obtain maximum profit for the whole recycling system. Economic values of recycled materials are considered in the method, and it is assumed that recycling values of materials from dismantling is higher than from shredding due to material quality losses at shredding.

The method is capable to generate information on what parts to be disassembled and in what sequence to reach the lowest cost/highest profit. The method is minimalistic in the sense it need only a small amount of input data on the product to be disassembled. The method is suitable for initial estimations on environmental and economical recyclability costs in, for example, Design for Recycling. A selected number of parts from a Volvo S60 are used in Forsberg [2004] to illustrate the method.

8 Discussion

In this report, design guidelines for recycling are suggested based on scenarios for some potential future recycling systems for ELV treatment. The choice of scenarios is made to reflect a wide range of potential recycling systems.

The actions of society together with the actors involved, such as the manufacturing and recycling industries, will affect the actual future. Different actors can have different opinions about prospects for the future and towards which future recycling system we should aim. There are several advantages for actors to aim in the same direction, for example, concerning investments in recycling technologies and concerning product development of vehicles.

Independent of scenario, we assume that shredder will remain a major process step in the recovery route of ELVs. We assume that the development of technologies for the SR treatment is a crucial part for the future recycling systems and will affect the share of components that are dismantled and the share of polymers that are sent for energy recovery. However, also in the most dismantling optimistic scenario, we assume that only about 10 % of the materials in an automobile is dismantled for recycling (except pre-treatment). In the energy recovery scenario, we assume that 15 % of the materials in an automobile is energy recovered.

The most probable scenario for the future is a mixture of technologies and solutions. Probably, there will be national, or sometimes even regional, solutions to what to do to fulfil the recovery and recycling quotas. The prerequisites, such as the amount of ELVs to be treated and the market for the fractions/materials that are sorted out for recovery or recycling as well as national/regional regulations on waste handling, differ largely from one country to another, sometimes even within the same country. In Southern Europe, there is no need for thermal energy in the same extent as in the Northern Europe. Legislation on what is classified as hazardous waste differs from country to country, as well as legislation on what waste can be put to landfill and in which amounts.

Recycle requirements are examples of policy instruments to reduce environmental impact and aiming to reach the environmental goals of the society. Recycling of materials is a strategy that can be used, for example, to increase the availability of resources and to reduce emissions, such as green house gases. However, the availability of resources is increased only if there is a demand of the recycled materials, which depends on the quality of the recycled materials, and the emissions of green house gases are reduces only if the emissions are reduced for the whole life cycle of the product and not, for example, only at the recycling of metals.

The demand of recycled materials (besides metals) cannot increase until the manufacturing industry starts to use recycled materials. An improved quality of recycled materials may increase the demand. It is no problem to preserve the quality of metals in society as long as virgin materials are added to the system [Holmberg, Johansson, and Karlsson, 2001]. Today, the use of metals, such as aluminium, is increasing and the mining of metals is necessary to fulfil this demand. In the future, the supply of virgin materials may not be as large as today and it may therefore be more relevant to consider the preservation of material quality at recycling also for metals.

Lighter vehicles, for example, including a larger share of plastics and composites, can imply a reduced use of fuels. However, it can be more difficult and more expensive to recycle such ELVs, according to the recycling requirements, and it can be more difficult to find a demand of the recycled materials. Consequently, the vehicle industries may avoid using such materials. In such cases there can be a contradiction between recycling requirements and environmental goals for climatic change.

9 Conclusions and recommendations

A strategy to reduce costs for ELV treatments is to increase the demand and value of recycled materials. The demand can be increased if the quality of recycled materials is improved. The quality of recycled materials depends on the recycling processes but also on the design of products, i.e. material choices and joining of components.

The choice and priority of design guidelines for recycling can be facilitated if they are combined with motives, such as:

- to increase the recycling or recovery quota;
- to facilitate and reduce costs for pre-treatment or dismantling;
- to increase the quality and demand of recycled materials.

The relevance of design guidelines for recycling can be improved by considering potential future recycling systems based on the expected lifetime of products. Different sets of design guidelines for recycling are relevant for different future recycling systems.

Some characteristics for the design guidelines based on the scenarios in this report are that:

- materials and components including hazardous substances (for example, mercury, lead, cadmium, and fluids) should primarily be avoided or otherwise be labelled and designed for disassembly, for example, to increase the quality of material fractions for recycling and energy recovery;
- PVC and copper should either be dismantled or be avoided in components that are not dismantled, for example in electrical cables, to increase the quality of material fractions for recycling and energy recovery;
- additional design for disassembly is usually unnecessary except for some few materials and components in a dismantling optimistic scenario, i.e. large parts of monomaterials or more valuable materials;
- the choice of plastics, including their additives and coatings, should be made to increase the quality and demand of recycled plastics;
- there is a low demand of recycled materials from composites, which implies that the use of composites should be avoided;
- few or none guidelines for recycling are needed when assuming best available technology.

Rail vehicles and trucks end up mainly in the same recycling system as automobiles and the same design guidelines can be used for large vehicles as for automobiles. However, the dismantling of materials and components from larger vehicles may be more extensive than for automobiles.

We propose that vehicle industries revise their existing guidelines according to relevant scenarios of future recycling systems. They can consider which design guidelines that are to be rejected, are missing, or should be complemented with information.

Design guidelines can be *rejected* if they are not considered relevant for any recycling system or if they are relevant only for some recycling system that is rejected by the manufacturing industry. Good contact between manufacturing and recycling industries can facilitate a common picture of the future recycling system and thus facilitate the identification of relevant guidelines for recycling. The future recycling system also depends on the society's future requirements on recycling, for example, compared to requirements on reduced emissions of green house gases and on preserved material quality of recycled materials.

Design guidelines, as they stand alone, often need some *complementary information* to be useful for designers, which should be based on conditions in potential future recycling systems. Examples of complementary information are which materials are recyclable or compatible with each other, which materials and components should be designed for disassembly, and specified information on how materials and components should be joined to facilitate separation at shredding. In this context, we recommend:

- a continued work on formulating a common definition on material recycling and energy recovery;
- a standardised system for the transport sector for labelling and identification of components including hazardous substances.

Examples of design guidelines that can be *missing* are:

- choice of plastics (based on their densities) to facilitate separation at SR treatment and to increase the quality and demand of recycled metals;
- choice of metal alloys to increase the quality and demand of recycled metals, for example, avoid rare alloying elements that can reduce the quality of other alloys.

10 References

ACEA, 2002. Recycling Infrastructure and Post Shredder Technologies – Final Report. Association des Constructeurs Européens d' Automobiles / European Automobile Manufacturers Association, Brussels

AFR, 1999. *Impurity Accumulation as a Consequence of Increased Scrap Recycling*, Survey. AFR-report 249, Viklund-White, C. and Menad, N., Minerals and Metals Recycling Research Centre, Luleå University of Technology

Andersson, B. and Jonson, U., 2004. ELV treatment. SAAB Automobile, Trollhättan

Anonymous, 1997. Mutabor Treatment of Shredder Light Fluff. EUWID Recycling: 34 (19. Aug), p2-4

Anonymous, 1998. ECRIS – ett forskningsprojekt för miljöanpassad bilåtervinning 1994-1998. Report 98.17

Anonymous, 1999. Shredder residue - Froth flotation. Abstract of APC Project, MBA, Ca, US

Anonymous, 2001. Shredder Waste Recycling. LIFE98 ENV/S/476, EU LIFE Environment programme

Anonymous, 2004. Price data. Plastic News and Recycling Times

API, 2004. The Alliance for the Polyurethanes Industry. Information published at the website: http://www.polyurethane.org

APME/EUCAR, 2003. Plastics in End-of-Life Vehicles. http://www.plastics-in-elv.org/

Argonne's Industrial Technology Development Division, 1998. Mixed Plastics Go Their Separate Ways, Process frees valuable but hard-to-isolate plastics. Volume 9, Number 1, 1998. http://www.techtransfer.anl.gov/highlights/9-1/recylabs.html

Axsäter, M., 2004. Laws related to the recycling of end-of-life vehicles. SAAB Automobile, Trollhättan

BIR, 2004. Shredding and media separation. BIR, Bureau of International Recycling, website, http://www.bir.org/

Barsoum, Karim, 2003. Vägverket, Sweden (karim.barsoum@vv.se, +46 (019) 192656)

Bayer material science, 2004. Webpage of Makrolon (http://www.makrolon.co.uk/index.cfm/page/17/title/CD_CD_-_R_DVD.htm)

Bontoux, L. and Leone, F., 1997. IPTS, the legal definitions of waste and their impact on waste management in Europe. Institute for Prospective Technological Studies, European Commission, Joint Research Center Sevilla, Sevilla

Bouwman, M.E. and Moll, H.C., 1998. Status quo and expectations concerning the material composition of road vehicles and consequences for energy use. Rijksuniversiteit, Groningen. (http://www.fwn.rug.nl/ivem/reports/rsrp_91.pdf)

Bröte, S., 1998. Disassembly systems – Process analysis and strategic considerations. Licentiate thesis, Department of Mechanical Engineering, Linköpings Universitet, Sweden

Celdhuizen Mark von, 2003. proj manager for recycling, ARN, Auto Recycling Netherlands, The Netherlands (0031 (0)20 6613181, info@ARN.NL)

Christill, M., 1998. SR-Pyrolysis Using Schwel/Brenn-technology. Siemens-KWU, Germany

Composite, 2004. Information published at the website of the COMPOSIT Thematic Network: http://www.compositn.net/index.htm

Copper Development Association, 2001. *The U.S. Copper-base Scrap Industry And Its By-products –An overview*, Technical report

Degré, J.P. (Holderbank, CH), 1998. "Recovery of (A)SR – (Automotive) Shredder Residue. Report. Schweiz

Domini, P., 200X. Handbok för konstruktörer. Stena Gotthard, Sweden

ELV network, 2004. Papers on material recycling, Webpage of ELV network (www.plastics-in-elv.org)

Eriksson, Lennart, 2003. Outokumpu Copper AB, personal contact.

ETA, 2004. Information published at the website of the European Tyre Recycling Association: http://www.etra.eu.com

EU, 1999. *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste*. Official Journal of the European Communities

EU, 2000. *Mechanical Recycling of PVC Waste, Final Report*. Study for DG XI of the European Commission, B4-3040/98/000821/MAR/E3, 591-5263

EU, 2002. *State-of-the-art report 2002*. Targeted Research Action on Polymer Materials, Thematic Network Type 2, Woubrugge, The Netherlands

Euro-Moulders, 2002. *Polyurethane car components: the options for ELV recycling and recovery*. Euro-Moulders.http://www.euro-moulders.org

European Commission - DG XII, and a Consortium of Automotive companies, Plastics resin producers, Dismantlers, Shredders, Recyclers, Molders of plastics parts, Energy users and Research Institutes, 1999. "European Information Network for the development of Eco-efficient Treatment of End of Life Vehicles with emphasis on Plastics". Final report

European Copper Institute, 2004. Information about innovations and the market published at the website

European Information Network for the Development of Eco-Efficient Treatment of End of Life Vehicles with the Emphasis on Plastics, 1999. Shredder residue treatment and use. Preliminary report

European Information Network for the Development of Eco-effcient Treatment of End of Life Vehicles with the Emphasis on Plastics, 2000. Dismantling. Preliminary report/working document

Fichtner Engineering Company, Germany, 1998. Validation of pre-treatment processes for shredder residues. A study commissioned by APME, Brussels

Forsberg, P., 2004. Recycling profitability optimisation using genetic algorithms. Mechatronics division, Chalmers University of Technology, Göteborg

Forss, T. and Terselius, B., 1994. Design for disassembly – Fastening and joining methods in plastics engineering. AFR Report 49, Swedish Waste Research Council, Stockholm

Francois, O. (Group Galloo Recycling, Belgium), 2003. Mass-Balance in Post-Shredding Technology: Results of a Trial Based on the Shredding of 201 ELVs – A Joint Work of Galloo, PSA and Renault. Recycling '03 Geneva, March 12-14, 2003

Franzén, B., 2001. A support method for the design of diassembly friendly products – With regard to ecology and economy. PhD thesis, Department of Mechanical Engineering, Linköpings Universitet, Sweden

Gazzo, A., Pétapermal, N., and Schmeitzky, C., 2003. Economic study of the management of End-of-Life Vehicles. Final Report, Commissioned by ADEME. Ernst and Young

GEPVP, 2004. *Recycling of End-of-Life Vehicle Glazing*. European Association of Flat Glass Manufacturers, Brussels, Belgium

Harbers, F., 2003. *The "European Composite Recycling Concept"*. 6. Internationale AVK-TV Tagung, Baden-Baden 2003

Heikkilä, K., 2004. Hazardous substances in materials of trucks. Volvo, Göteborg

Henriksson, Hans, 2003. Boliden Mineral AB, personal contact

Henton, J. (ICI Technology), 1998. ASR treatment. Thematic Network, Energy Recovery Group meeting, Lyon 28 Jan. 1998

Holmberg, J, Johansson J. and Karlsson, S., 2001. *Material Flow Quality – Managing Aluminium Alloy Recycling*. Presentation at the International Society for Industrial Ecology Inaugural Meeting, Noordwijkerhout, The Netherlands, Nov 12-14, 2001.

Hultberg Tommy, 2002. Avregistrerade lastbilar med totalvikt över 3,5 ton efter fabrikat, totalvikt, årsmodell och avregistrerings orsak. Bil Sweden, Stockholm.
Hultberg Tommy, 2003. Bil Sweden, Stockholm (Tommy.Hultberg@bilsweden.se, +46 (08) 7016333)

International Organization for Standardization, 2001. Road vehicles – Recyclability and recoverability – Calculation method. ISO 22628. International Organization for Standardization, Geneva

Jansen Rieks, 2003. Auto Recycling Nederland, Research Center Amstelveen, Amstelveen (arnresearchcenter@zonnet.nl, rieks.jansen@arn.nl, 0031(0)20-5035080, www.arn.nl)

Jansson, A., 2000. Recycling and degradation of thermoplastic materials and polymer
recycling. Chalmers University of Technology, Göteborg

Jenseit, W., Stahl, H., Wollny, V., and Wittlinger, R., 2003. Recycling and recovery options for ELV plastic parts. Öko-institut, Darmstadt

Klintbom, P. and Wahlström, D., 2001. Screening LCA 2285. Volvo, Report ER-59883 (Company use only)

Kondo, Y., Miki, K., Hirai, K., and Obata, F., 2000. A disassembly and recyclable assessment tool for industrial products with complex structure. International Journal of Environmentally Conscious Design and Manufacturing, Vol. 8, No.4, pp39-45

Laar Franklin van de, 2003. General Secretary STIBA, DG 's-Hertogenbosch - Brink 7 5236 AR Empel (franklinvdlaar@stiba.nl, +31 73-641 00 75)

Lagerstedt, J., 2004. Design for Environment Guidelines. 3EST 7-3049, Bombardier Transportation, Sweden

Landner, L. and Lindeström, L., 1999. *Copper in society and in the environment- an account of the facts on fluxes, amounts and effects of copper in Sweden.* 2nd Revised Edition, Swedish Environmental Research Group (MFG). Scandinavian Copper Development Association, Västerås, Sweden

Large, O. and Zariatti, S. (SOFIVAL), 1999. New Automobile Shredder Residue Recycling Processes. in Recycling '99 Proceedings, Vol II, p. II 265-270. Geneva

Larsson, Y., 2003. *Summary of Recycling of Composite Materials in Transport 2003*. Intercity Trains, CoC DfE, Bombardier Transportation, Sweden

Larsson, Y., 2004. Bombardier Transportation experiences of end of life treatment of rail vehicles. Bombardier Transportation, Västerås

Larsson, Y., 2004. Recycling information about different composites. Bombardier Transportation, Västerås

Liljenroth, U., 1999. ECRIS project – energy recovery report. Volvo Car Corporation, Gothenburg

Liljenroth, U., 2004. Shredder technology – Development and trends in Europe. WSP Environmental, Göteborg

Luxus Limited, 2004. Webpage of Luxus Limited (http://www.luxus.co.uk/Info_Processes.htm)

Margon, V., 2004. Supercritical carbon dioxide assisted extraction for chemical recycling of polycarbonate. NUR913. Technische Universiteit, Eindhoven

Mark, F.E., 1998. Thermal recovery of (A)SR – A way forward to ELVs management. BHM, 143. Jg., Heft 1. Germany

Mark, F.E. and Kamprath, A., 2000. *Recycling & Recovery Options for PU Seating Material: A Joint Study of ISOPA/Euro-Moulders*. SAE Technical, Paper Series 2000-01-1514, ISOPA

Miljödepartementet, 2001. Resurs i retur – Slutrapport från utredningen för översyn av producentansvaret. SOU 2001:102, Statens offentliga utredningar, Stockholm

Nijkerk, A., 1998. New development in shredder technology. Recycling International, Oct., p.20-29

Otdjian Christiane, 2003. Environmental Affairs, RENAULT V.I.VENISSIEUX, France (+33 472 968527)

Pilkington, 2004. http://www.pilkington.com/

Plastics in ELV, 2002. Montello process. Plastics in ELV, Italy, http://www.plastics-in-elv.org/

Plastics news, 2004. Resin pricing, Webpage of Plastics news, (http://www.plasticsnews.com/subscriber/resin)

Plastics Technology, 2004. Resin pricing, Webpage of Plastics Technology (www.plasticstechnology.com/pricing)

Polymer-Chemie GmbH, 200X. Presentation material. Bad Sobernheim

Pro-plast, 2004. Webpage of Pro-plast (http://www.pro-plast.com/boerse)

Refiber, 2003. *Material and Thermal Recycling of Wind Turbine Blades and other fiberglass items by ReFiber ApS*. Presented by Erik Grove-Nielsen at ReFiber ApS in Denmark at the Recycling of Composite Materials in Transport conference the 16th June 2003 in Piteå, Sweden

Salyp, 2003. Recycling ASR. http://www.salypnet.com/p01o1110.htm

Sander, K., Jepsen, D., Schilling, S., and Tebert, C., 2004. Definition of waste recovery and disposal operations. Report compiled for the European Commission. Ökopol, Hamburg. (europa.eu.int/comm/environment/waste/studies/recovery_disposal.htm)

Scheirs, J., 1998. Polymer recycling. Wiley, England

Sciberras, G., 1999. Plastic sorting technologies. Project SUP'RB, which is the acronym for a jointed R&D project carried by six industrial partners: CFF, GALLOO, ELF ATOCHEM, HUTCHINSON, GIFAM and RENAULT. Identiplast, Brussels

Sjöberg, C., 2003a. Material: Glass. Volvo Car Corporation, Göteborg

Sjöberg, C., 2003b. Post-shredder treatment technologies. Volvo Technology Corporation, Göteborg

Sjöberg, C., 2004a. Material: PVC. Volvo Car Corporation, Göteborg

Sjöberg, C., 2004b. Trends in society concerning waste treatment and producer responsibility. Volvo Car Corporation, Göteborg

Society of Motor Manufacturers and Traders Ltd, 2001. Automotive Consortium on Recycling and Disposal (ACORD), Fourth Annual Report 2001 (Reporting 2000 Performance)

Spicer, Wang, Zamudio-Ramirez, and Daniels, 1997?. Disassembly modelling used to assess automotive recycling opportunities. SAE 970416

Stena Gotthard, 2001.Leveransbestämmelser skroträvaror. Stena Gotthard, Sweden (In Swedish)

Strömberg, K., 2000. Valuation of aluminium in the recycling system – Method development -modelling - software development. Master thesis, Department of Experimental Physics, Chalmers University of Technology and Göteborg University, Göteborg (In Swedish)

Strömberg, K. and Ringström, E., 2003. *Cost Benefit Analysis of Recycling Electrical and Electronic Equipment*. On commission of Stiftelsen Svenskt Kretslopp. CIT Ekologik AB, Chalmers Industriteknik, Göteborg

Strömberg, K., Rydberg, T., and Weiner, D. 2002. Valuation of recycled material in LCA/DfE applied to aluminium. Presented at the R'02 conference in Geneva, 12-15 February 2002. CIT Ekologik AB, Chalmers Science Park, Göteborg

Volvo Group, 2002. Substitutes for hazardous chemical substances. Volvo's white list. Standard STD 100-0004. (available on http://www.tech.volvo.se/standard/docs/100-0004.pdf)

Volvo Group, 2003. Chemical substances which must not be used within the Volvo Group. Volvo's black list. Standard STD 100-0002. (Available on http://www.tech.volvo.se/standard/docs/100-0002.pdf)

Volvo Group, 2004a. Generic identification and marking of plastics products. Standard STD 103-0002. (Available on http://www.tech.volvo.se/standard/docs/103-0002.pdf)

Volvo Group, 2004b. Chemical substances whose use within the Volvo Group shall be limited. Volvo's grey list. Standard STD 100-0003. (available on http://www.tech.volvo.se/standard/docs/100-0003.pdf)

Volvo Truck Corporation, 1997. Environmental Guidelines for Product Development. GDI 961-90. (Available on http://www.volvo.com/NR/rdonlyres/1747758C-D289-464C-A23A-36FB1EF72F46/0/handb_en.pdf)

Wendin, M., 2003. End of life for trucks in Europe and material recycling. Volvo, Göteborg

Appendix A

Laws related to the recycling of end-of-life vehicles

1. Introduction

Different laws affect and will affect the recycling of vehicles. Some of them are obvious like The European End-of-Life Vehicle Directive *(2000/53/EC)* but also other laws as the Swedish regulation on the landfilling of waste *(2001:512)*

This is a short summary of relevant laws and in some cases other documents related to recycling of vehicles. The focus is on the European Union (EU) and on the Member States of the EU.

The major problem to get a good overview of the legislation in different countries is to find the legislations translated into English. Therefore, this summary is not complete considering national laws in EU.

To make it easier to get an overview of the legislation only the most relevant parts are included.

The connection between some European legislation and Swedish can be found in Annex VI.

2. European Legislation

The European Communities' core objective of achieving European unification is based exclusively on the rule of law. Community law is an independent legal system that takes precedence over national legal provisions. A number of key players are involved in the process of implementing, monitoring and further developing this legal system for which a variety of procedures apply. In general, EU law is composed of three different - but interdependent - types of legislation:

- Primary legislation includes in particular the Treaties and other agreements having similar status (for example - 'Maastricht Treaty' 1992), the Single European Act (1987).

- Secondary legislation is based on the Treaties and implies a variety of procedures defined in different articles thereof. In the framework of the Treaties establishing the European Communities, Community law may take the following forms:

Regulations, which are directly applicable and binding in all EU Member States without the need for any national implementing legislation.

Directives, which bind Member States as to the objectives to be achieved within a certain time-limit while leaving the national authorities the choice of form and means to be used. Directives have to be implemented in national legislation in accordance with the procedures of the individual Member States.

Decisions, which are binding in all their aspects for those to whom they are addressed. Thus, decisions do not require national implementing legislation. A decision may be addressed to any or all Member States, to enterprises or to individuals.

Recommendations and *opinions,* which are not binding.

- Case-law includes judgments of the European Court of Justice and of the European Court of First Instance, for example, in response to referrals from the Commission, national courts of the Member States or individuals.

3. Producer Responsibility

3.1 ELV Laws

3.1.1 The end-of-life vehicle (ELV) Directive (2000/53/EC)

The main objective of this European Directive of the European Parliament and of the Council, of 18 September 2000, is the prevention of waste from vehicles, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles and especially the operators directly involved in the treatment of end-of life vehicles. The Directive includes issues on reuse, recycling and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste.

In order to promote the prevention of waste, Member States shall encourage,

- the vehicle manufacturers, in liaison with material and equipment manufacturers, to limit the use of hazardous substances in vehicles and to reduce them as far as possible from the conception of the vehicle onwards, so as in particular to prevent their release into the environment, make recycling easier, and avoid the need to dispose of hazardous waste,
- the design and production of new vehicles which take into full account and facilitate dismantling, reuse and recovery, in particular recycling of end-of life vehicles, their components and materials,
- vehicle manufacturers, in liaison with material and equipment manufacturers, to integrate an increasing quantity of recycled material in vehicles and other products, in order to develop the markets for recycled materials.

In article 4.2(a), it is stated that the Member States shall ensure that materials and components of vehicles put on the market after 1 July 2003 do not contain lead, mercury, cadmium or hexavalent chromium other than in cases listed in Annex II under the conditions specified therein (see Annex IV in this report).

The delivery of the vehicle to an authorised treatment facility shall occur without any cost for the last holder and/or owner as a result of the vehicle having no or a negative market value.
The producers shall meet all, or a significant part of, the costs of the implementation of this measure and/or take back end-of life vehicles.

The establishment or undertaking carrying out treatment operations shall fulfil at least the following obligations in accordance with Annex I (see Annex V in this report):

- end-of life vehicles shall be stripped before further treatment or other equivalent arrangements are made in order to reduce any adverse impact on the environment,
- components or materials labelled or otherwise made identifiable shall be stripped before further treatment,
- hazardous materials and components shall be removed and segregated in a selective way so as not to contaminate subsequent shredder waste from end-of life vehicles,
- stripping operations and storage shall be carried out in such a way as to ensure the suitability of vehicle components for reuse and recovery, and in particular for recycling,
- treatment operations for depollution of end-of life vehicles as referred to in Annex I(3) shall be carried out as soon as possible (Annex V 3 in this report).

Member States shall take the necessary measures to encourage the reuse of components that are suitable for reuse, the recovery of components that cannot be reused and the giving of preference to recycling when environmentally viable, without prejudice to requirements regarding the safety of vehicles and environmental requirements such as air emissions and noise control.
Member States shall take the necessary measures to ensure that the following targets are attained by economic operators:

- no later than 1 January 2006, for all end-of life vehicles, the reuse and recovery shall be increased to a minimum of 85 % by an average weight per vehicle and year. Within the same time limit the reuse and recycling shall be increased to a minimum of 80 % by an average weight per vehicle and year,
  for vehicles produced before 1 January 1980, Member States may lay down lower targets, but not

lower than 75 % for reuse and recovery and not lower than 70 % for reuse and recycling. Member States making use of this subparagraph shall inform the Commission and the other Member States of the reasons therefore,

- no later than 1 January 2015, for all end-of life vehicles, the reuse and recovery shall be increased to a minimum of 95 % by an average weight per vehicle and year. Within the same time limit, the re-use and recycling shall be increased to a minimum of 85 % by an average weight per vehicle and year.

The law also regulates collection, coding standards/dismantling information and reporting and information.

3.1.2 Swedish Regulation on producer responsibility for vehicles (1997:788)

This Swedish Regulation, together with the Swedish Regulation on ban on certain metals in vehicles (SFS 2003:208, not included in this report), is similar to the European ELV Directive. However there are two major exemptions; producer responsibility for new vehicles as of 1998 and it require that vehicles shall be recycled to 85% as of 2002.

3.1.3 Law on Recycling of End-Of-Life Vehicles (Japan)

The Japanese law contains chapters about;

- Implementation of Resource Recycling[1] etc
- Registration and Licensing (Registration of Handling agents & Fluorocarbons recoverers, Licensing of Dismantlers & Shredders)
- Deposit for resource Recycling
- Reporting requirements on auto transfer,
- Etc

Major issues are;

Responsibility of Automakers etc; Automakers etc must endeavor to promote longer use of vehicles, while facilitating resource recycling etc of end-of-life vehicles and reducing the cost required for the resource recycling etc, by appropriately designing automobiles and the types of components and raw material.

Responsibility of car owner; Owners of automobiles must seek to generate fewer end-of-life vehicles (ELV) through longer use of vehicles, and to promote resource recycling, etc of ELV by, upon auto purchase, selecting cars manufactured with resource recycling in mind, and, upon auto repair, using materials obtained by resource recycling of ELV and parts utilizing such materials.

Obligation to hand over ELVs

Obligation to destroy Fluorocarbons

Obligation to pay deposit for resource recycling etc; Owners of automobile must deposit money in the amount equivalent to the resource recycling fee. The fee depends on if the vehicle have air conditioner and/or specified recovery articles

Dismantlers obligation to implement resource recycling; A dismantler, when dismantling ELVs, must separate from ELVs the useful components and render them ready for use as components or other parts of products, and must implement other forms of resource recycling.

Shredders obligation to implement resource recycling; A shredder, when shredding dismantled vehicles he has accepted, must separate useful metals from dismantled vehicles and render them available for use as raw materials, or adopt other methods for resource recycling. The resource recycling must be undertaken in accordance with the standards concerning resource recycling of dismantled vehicles, stipulated by the order of a competent ministry.

[1] "Resource recycling" in this Law indicates the following acts:
(1) Acts of rendering an entire, or a part of, end-of-life vehicle, dismantled vehicle, or specified article for resource recycling, available for use as raw materials, components or other parts of products;
(2) Acts of rendering an entire, or a part of, end-of-life vehicle, dismantled vehicle, or specified article for resource recycling, which can be used as a fuel or has a potential to be used as a fuel, available for use as such.
"Resource recycling, etc." in this Law means resource recycling and the destruction of fluorocarbons.

Obligation of Automakers etc to accept; If an automaker etc is asked by fluorocarbons recoverers, dismantlers or shredders to take in specified articles for resource recycling etc derived from automobiles it manufactured, the automaker etc must take in the articles etc delivered for resource recycling.

3.2 Laws related to the ELV Directive

3.2.1 Swedish Ordinance on producer responsibility for tyres (1994:1236)

Producer responsibility for tyres is also regulated in the European ELV Directive (2000/53/EC) and in the Directive on the landfill of waste (1999/31/EC) in which landfilling of tyres is forbidden.

3.2.2 Decision on minimum requirements for the certificate of destruction on end-of-life vehicles (2002/151/EC)

This European Commission Decision, of 19 February 2002, is issued by the European Parliament and of the Council on end-of-life vehicles in accordance with the ELV Directive (2000/53/EC), Article 5(3). The certificate of destruction is required to contain information on address etc of the establishment that is issuing the certificate and of the authority that is responsible for the permit, class of vehicle, chassi no etc.

3.2.3 Decision on establishing component and material coding standards for vehicles (2003/138/EC)

This is a European Commission Decision of 27 February 2003 for vehicles pursuant to the ELV Directive (2000/53/EC) of the European Parliament and of the Council on end-of-life vehicles. The Decision says that producers, in concert with material and equipment manufacturers, shall use the nomenclature of ISO component and material coding standards referred to in the Annex to this Decision for the labelling and identification of components and materials of vehicles, e.g. for plastics with a weight of more than 100g and for rubbers (except tyres) and lattices with a weight of more than 200g.

Two years after the entry into force of this Decision (i.e. 1 July 2005) on the basis of the practical experience gained in the recycling and recovery of end-of-life vehicles, the present Decision shall be reviewed in order to establish, if necessary, component and material coding standards for other materials.

3.2.4 Decision concerning a questionnaire for Member States reports on the implementation of the ELV Directive (2001/753/EC)

This is a European Commission Decision, of 17 October 2001, of the European Parliament and of the Council on end-of -life vehicles. The Decision says that the Member States shall draw up their reports on the implementation of the ELV Directive (2000/53/EC).The questions are about:

- incorporation into National Law,
- implementation of the Directive, for example available information on types and quantities of recycled materials in vehicles and in other products as well as on the market situation for recycled materials, information on the rates of reuse, recycling and recovery attained in each calendar year of the reference period.

3.2.5. Danish Statutory order on import and sale of passenger cars, light trucks, etc. containing certain hazardous substances (No. 570 of 23 June 2003.)

This Danish law is different from the European ELV Directive (2000/53/EC), Annex II, regarding one issue; 12. b. Copper in friction materials in brake linings with a lead content not exceeding 0.4 per cent by weight. Expiry date of the exemption is 01.01.2007. The exemptions no. 12b shall only apply if the substance has not been added with the aim of giving the final product a particular characteristic or appearance. The exemption date is 6 months earlier than in the ELV Directive.

3.3 Other laws regarding Producer responsibility

3.3.1 Directive on waste electrical and electronic equipment (WEEE)(2002/96/EC)

This European Directive of the European Parliament and of the Council, of 27 January 2003, does not regulate the electrical or electronic equipment in the vehicles when put on the market.

3.3.2 Swedish Regulation on producer responsibility on electrical and electronic equipment (2000:208)

This is the Swedish WEEE Regulation, and it is similar to the European WEEE Directive (2002/96/EC).

3.3.3 Decision on establishing the conditions for a derogation for glass packaging in relation to the heavy metal concentration levels established on packaging and packaging waste (2001/171/EC)

This European Commission Decision, of 19 February 2001, allow glass packaging to exceed the limits for lead, cadmium, mercury or hexavalent chromium, in the Directive on packaging and packaging waste (95/62/EC) (not included in this report) if they are not intentionally introduced during the manufacturing process. The packaging material may only exceed the concentration limits because of the addition of recycled materials. This Decision is included in this report because a similar law for polymers might make the recycling of polymers easier.

3.4 Other documents related to Producer responsibility

3.4.1 Decision on laying down the Sixth Community Environment Action Programme (No 1600/2002/EC)

This is a Decision of the European Parliament and of the Council of 22 July 2002. This European Programme contains different objectives and priority areas, for example, chemicals and sustainable use and management of natural resources and wastes. This might affect future legislation, which can affect producer responsibility, waste management and the use of hazardous substances.

Chemicals, for example;

- placing the responsibility on manufacturers, importers and downstream users for generating knowledge about all chemicals (duty of care) and assessing risks of their use, including in products, as well as recovery and disposal.

Sustainable use and management of natural resources and wastes, for example;

- achieving a significant overall reduction in the volumes of waste generated through waste prevention initiatives, better resource efficiency and a shift towards more sustainable production and consumption patterns,
- a significant reduction in the quantity of waste going to disposal and the volumes of hazardous waste produced while avoiding an increase of emissions to air, water and soil,
- encouraging re-use and for wastes that are still generated: the level of their hazardousness should be reduced and they should present as little risk as possible; preference should be given to recovery and especially to recycling; the quantity of waste for disposal should be minimised and should be safely disposed of; waste intended for disposal should be treated as closely as possible to the place of its generation, to the extent that this does not lead to a decrease in the efficiency in waste treatment operations.

The programme also includes actions on how to achieve the above mentioned goals.

4. Hazardous substances

4.1 Electrical and electronic equipment

4.1.1 Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (2002/95/EC)

This European Directive of the European Parliament and of the Council, of 27 January 2003, states that from the 1st of July 2006, new electrical and electronic equipment put on the market shall not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), or polybrominated diphenyl ethers (PBDE) (Article 4). Exemptions are for example; mercury in lamps, lead as an alloying element in steel and copper (same as the ELV Directive), lead as an alloying element in aluminium in a maximum of 0.4 % by weight, lead in electronic ceramic parts (e.g. piezoelectronic devices).

Before the 13th of February 2005, the Commission shall review the measures provided for in this Directive to take into account. Particular attention shall be paid during the review to the impact on the environment and on human health of other hazardous substances and materials used in electrical and electronic equipment. The Commission shall examine the feasibility of replacing such substances and materials and shall present proposals to the European Parliament and to the Council in order to extend the scope of Article 4, as appropriate.

This Directive does not apply to vehicles, but the ELV Directive might be adapted to this.

4.2 Batteries and accumulators

4.2.1 Directive on batteries and accumulators containing certain dangerous substances (91/157/EEC)

This European Council Directive, of 18 March 1991, regulates the usage of batteries with more than 0.0005 weight-% Hg, or more than 0.025 weight-% Cd, or more than 0.4 weight-% Pb. (According to the ELV Directive (2000/53/EC), cadmium is not allowed in electrical vehicles put on the market after 31 December 2005. Other usage of cadmium or mercury in batteries are not allowed. Lead is allowed in batteries but must be labelled or made identifiable in accordance with Article 4(2)(b)(iv)). Member States shall ensure an efficient organization of separate collection and, where appropriate, the setting up of a deposit system.

4.2.2 Swedish regulation on batteries (1997:645)

This Swedish Regulation is similar to the European Directive on batteries and accumulators containing certain dangerous substances (91/157/EEC). This Regulation also states that the producer, importer or seller of lead batteries with a weight over 3 kg have to take care of these batteries when discarded and to transport them to a facility for disposal or recycling. Used batteries shall not be part of or kept together with other waste. A fee of 30 SKr has to be paid for each storage battery.

4.3 Waste oils

4.3.1 Directive on the disposal of waste oils (75/439/EEC, amendment 87/101/EEC)

This European Council Directive, of 22 December 1986, amending Directive 75/439/EEC, states that Member States shall take the necessary measures to give priority to the processing of waste oils by regeneration where technical, economic and organizational constraints so allow. Where waste oils are not regenerated Member States shall take the measures necessary to ensure that any combustion of waste oils is carried out under environmentally acceptable conditions, in accordance with the provisions of this Directive, provided that such combustion is technically, economically and organizationally feasible. Where waste oils are neither regenerated nor burned, Member States shall take the measures necessary to ensure their safe destruction or their controlled storage or tipping.
Member States shall take the necessary measures to ensure the prohibition of:

- any discharge of waste oils into internal surface waters, ground water, coastal waters and drainage systems,
- any deposit and/or discharge of waste oils harmful to the soil and any uncontrolled discharge of residues resulting from the processing of waste oils,
- any processing of waste oils causing air pollution which exceeds the level prescribed by existing provisions.

Where waste oils are regenerated, Member States shall take the measures necessary to ensure that the operation of the regeneration plant will not cause avoidable damage to the environment and that the base oils derived from regeneration do not constitute a toxic and dangerous waste.

Any establishment producing, collecting and/or disposing of more than a given quantity of waste oils per year, to be specified by each Member State but not higher than 500 litres, must:

- keep a record of the quantity, quality, origin and location of such oils and of their despatch and receipt, including the dates of the latter and/or
- convey such information to the competent authorities on request.

4.4. Mercury

*4.4.1 Act to prevent Mercury Emissions when Recycling and Disposing of Motor Vehicles, in Maine, USA (*Sec. 1. 38 MRSA §1665, §1662)

This Maine (USA) Act states that components with mercury have to be labelled, and that mercury switches are not allowed. No later than June 30, 2004, and annually thereafter, motor vehicle manufacturers shall report in writing to the department on the results of the source separation program. The report must include, at a minimum, the numbers of mercury-added components removed and recycled from motor vehicles during the previous calendar year compared to the estimated numbers of components potentially available for collection.

5. Waste

5.1 Waste

5.1.1 Directive on waste (75/442/EEC, amendment 91/156/EEC)

This European Council Directive, of 18 March 1991, states that the Member States shall take appropriate measures to encourage:

firstly, the prevention or reduction of waste production and its harmfulness, in particular by:

- the development of clean technologies more sparing in their use of natural resources,
- the technical development and marketing of products designed so as to make no contribution or to make the smallest possible contribution, by the nature of their manufacture, use or final disposal, to increasing the amount or harmfulness of waste and pollution hazards,
  - the development of appropriate techniques for the final disposal of dangerous substances contained in waste destined for recovery.

secondly:

- the recovery of waste by means of recycling, re-use or reclamation or any other process with a view to extracting secondary raw materials, or
- the use of waste as a source of energy.

Waste shall be recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular without risk to water, air, soil, plants and animals, without causing a nuisance through noise or odours,
and without adversely affecting the countryside or places of special interest.

Member States shall also take the necessary measures to prohibit the abandonment, dumping or uncontrolled disposal of waste.

In accordance with the "polluter pays" principle, the cost of disposing of waste must be borne by the holder who has waste handled by a waste collector or by an undertaking that carries out the operations listed in Annex II A or B (Annex II and III in this report) or recovers or disposes of it himself in accordance with the provisions of this Directive, and/or the previous holders or the producer of the product from where the waste came.

5.2 Hazardous Waste

5.2.1 Decision on establishing a list of wastes and establishing a list of hazardous waste (2000/532/EEC)

This European Commission decision, of 3 May 2000, defines the classification of waste and hazardous waste. (The decision is replacing Decision 94/3/EC. The establishment of a list of wastes is pursuant to the Council Directive on waste, Article 1(a), (75/442/EEC) and the Council Decision 94/904/EC. And the establishment of a list of hazardous waste is pursuant to the Council Directive on hazardous waste, Article 1(4), (91/689/EEC).)

Examples of hazardous waste are wastes from shredding of metal-containing wastes, fluff-light fraction, and dust containing dangerous substances. Fluff-light fraction and dust other than those are classified as non-hazardous. A complete list can be found in the Annex of this Directive (which is not included in this report).

5.2.2 Directive on hazardous waste (91/689/EEC)

This European Council Directive, of 12 December 1991, states that Member States shall ensure that hazardous waste is recorded and identified. They shall also ensure that different categories of hazardous waste are not mixed and that hazardous waste is not mixed with non-hazardous waste, save where the necessary measures have been taken to safeguard human health and the environment. Any establishment or undertaking that carries out disposal operations must obtain a permit. This applies also in the case of operations that may lead to recovery. However, the permit requirement may be waived in the latter case if the method of recovery is such that there is no danger to human health or the environment, or if the Member State has adopted general measures laying down conditions for various methods of recovery, provided the conditions have been communicated to the Commission.

4.3 Landfill of waste

5.3.1 Directive on the landfill of waste (1999/31/EC)

This European Council Directive, of 26 April 1999, states that each landfill shall be classified in one of the following classes: landfill for hazardous waste, landfill for non-hazardous waste, or landfill for inert waste.

Only waste that has been subject to treatment shall be landfilled. This provision may not apply to inert waste for which treatment is not technically feasible. Other exemptions are also possible. Only hazardous waste that fulfils the criteria set out in accordance with Annex II in this Directive shall be assigned to a hazardous landfill. Landfill for non-hazardous waste may be used for municipal waste and non-hazardous waste of any other origin, which fulfil the criteria for the acceptance of waste at landfill for non-hazardous waste set out in accordance with Annex II.

Annex II: The following general guidelines can be used to set preliminary criteria for acceptance of waste at the three major classes of landfill or the corresponding lists. Specific criteria and/or test methods and associated limit values for each class of landfill is set out in the decision on establishing criteria and procedures for the acceptance of waste at landfills (2003/33/EC).

- Inert waste landfills: Only inert waste.
- Non-hazardous waste landfills: In order to be accepted, a waste type must not be covered by the directive on hazardous waste (91/689/EEC).
- Hazardous waste landfills: Preliminary, hazardous waste landfills would consist of only those waste types covered by the directive on hazardous waste (91/689/EEC). Such waste types should, however not be accepted without prior treatment if they exhibit total contents or leachability of potentially hazardous components that are high enough to constitute a short-term occupational or environmental risk or to prevent sufficient waste stabilisation within the projected lifetime of the landfill.

The following wastes are not accepted in a landfill; liquid waste, waste which, in the conditions of landfill, is explosive, corrosive, oxidising, highly flammable or flammable, as defined in Annex III of the directive on hazardous waste (91/689/EEC), whole used tyres, excluding tyres used as engineering material, and shredded used tyres five years from the date laid down in Article 18(1) (excluding in both instances bicycle tyres and tyres with an outside diameter above 1 400 mm). (According to Article 18(1), Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive not later than two years after its entry into force).

The dilution of mixture of waste solely in order to meet the waste acceptance criteria is prohibited.
Member States shall set up a national strategy for the implementation of the reduction of biodegradable waste going to landfills. This strategy should include measures to achieve the targets set out in the following paragraph by means of in particular, recycling, composting, biogas production or materials/energy recovery.
Not later than five years after the date laid down in Article 18(1), biodegradable municipal waste going to landfills must be reduced to 75 % of the total amount (by weight) of biodegradable municipal waste produced in 1995 or the latest year before 1995 for which standardised Eurostat data is available. In eight years, the waste must be reduced to 50% and in 15 years to 35%.

All of the costs involved in the setting up and operation of a landfill site, including as far as possible the cost of the financial security or its equivalent referred to in Article 8(a)(iv), and the estimated costs of the closure and after-care of the site for a period of at least 30 years shall be covered by the price to be charged by the operator for the disposal of any type of waste in that site.

Part of the monitoring is to analyse the leachate. Recommended parameters are: ph, TOC, phenols, heavy metals, fluoride, AS, and oil/hydrocarbons.

5.3.2 Swedish regulation on the landilling of waste (2001:512)

This Swedish regulation is similar to the European directive on the landfilling of waste (1999/31/EC). A mayor difference is that sorted burnable waste is not allowed to landfill as of 1 January 2002 and that organic waste is not allowed to landfill from 1 January 2005.

5.3.3 Decision on establishing criteria and procedures for the acceptance of waste at landfills (2003/33/EC)

This European Council decision, of 19 December 2002, establish the specific criteria and/or test methods and associated limit values for each class of landfill and for acceptance of waste at landfills. The leaching limits contain values for heavy metals as for example Cd, Pb, Hg, and Cr and also for other substances as for example chloride. (The decision is in accordance with the principles set out in the directive on the landfilling of waste (1999/31/EC), Article 16 and Annex II.) The decision shall take effect on 16 July 2004. Member States shall apply the criteria set out in section 2 of the Annex to this Decision by 16 July 2005.

5.4 Incineration of Waste

*5.4.1 Directive on the incineration of waste (*2000/76/EC)

This European Directive of the European Parliament and of the Council, of 4 December 2000, covers incineration and co-incineration plants. The directive already apply for new plants. For existing plants this Directive shall apply as from 28 December 2005.

The aim of this Directive is to prevent or to limit as far as practicable negative effects on the environment, in particular pollution by emissions into air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste.

This aim shall be met by means of stringent operational conditions and technical requirements, through setting emission limit values for waste incineration and co-incineration plants within the Community and also through meeting the requirements of the directive on waste (75/442/EEC).

The law containes limit values for heavy metals as Cd, Hg, Pb, and Cr and other substances as for example dioxines.

- Cement kilns with co-incineration of waste; limit values for Cd, Hg, Pb, Cr, and dioxines etc.
- Combustion plants with co-incineration of waste; limit values for Cd, Hg, Pb, Cr, and dioxines etc.
- Industrial sectors not covered above with co-incineration of waste; Cd, Hg ,and dioxines etc.
- Emission limit values for discharges of waste water from the cleaning of exhaust gases; Hg, Cd, Pb, Cr, and dioxins etc.
- Air emission limit values; Cd, Hg, Pb, Cr, and dioxines etc

If hazardous wastes with a content of more than 1 % of halogenated organic substances, expressed as chlorine, are co-incinerated, the temperature has to be raised to 1100 °C.

5.4.2. Swedish regulation on the incineration of waste (2002:1060*)*

This Swedish regulation is similar to the European directive on the incineration of waste (2000/76/EC).

5.5 Other waste regulations

5.5.1 Regulation on waste statistics (No 2150/2002*)*

This European regulation of the European Parliament and of the Council, of 25 November 2002, requires the Member States and the Commission, in their respective fields of competence, to produce statistics on:

- waste production (in accordance with Annex I to the Regulation); for example discarded vehicles are classified as a waste category such as household waste, batteries and accumulators.
- - recovery and disposal of waste (in accordance with Annex II to the Regulation); for example incineration, recovery, recycling, deposit.
- import and export of waste (in accordance with Annex III to the Regulation); for example used motor oils, metallic waste, used tyres, discarded vehicle.

The Annexes I and II to the Regulation are not included in this report.

ANNEX I

CATEGORIES OF WASTE (Council Directive 91/156/EEC of 18 March 1991 amending Directive 75/442/EEC on waste, Annex I)

Q1 Production or consumption residues not otherwise specified below
Q2 Off-specification products
Q3 Products whose date for appropriate use has expired
Q4 Materials spilled, lost or having undergone other mishap, including any materials, equipment, etc., contaminated as a result of the mishap
Q5 Materials contaminated or soiled as a result of planned actions (e.g. residues from cleaning operations, packing materials, containers, etc.)
Q6 Unusable parts (e.g. reject batteries, exhausted catalysts, etc.)
Q7 Substances which no longer perform satisfactorily (e.g. contaminated acids, contaminated solvents, exhausted tempering salts, etc.)
Q8 Residues of industrial processes (e.g. slags, still bottoms, etc.)
Q9 Residues from pollution abatement processes (e.g. scrubber sludges, baghouse dusts, spent filters, etc.)
Q10 Machining/finishing residues (e.g. lathe turnings, mill scales, etc.)
Q11 Residues from raw materials extraction and processing (e.g. mining residues, oil field slops, etc.)
Q12 Adulterated materials (e.g. oils contaminated with PCBs, etc.)
Q13 Any materials, substances or products whose use has been banned by law
Q14 Products for which the holder has no further use (e.g. agricultural, household, office, commercial and shop discards, etc.)
Q15 Contaminated materials, substances or products resulting from remedial action with respect to land
Q16 Any materials, substances or products which are not contained in the above categories.

ANNEX II

DISPOSAL OPERATIONS (96/350/EC: Commission Decision of 24 May 1996 adapting Annexes IIA and IIB to Council Directive 75/442/EEC on waste, Annex IIA).

NB: This Annex is intended to list disposal operations such as they occur in practice. In accordance with Article 4 (Annex III in this report) waste must be disposed of without endangering human health and without the use of processes or methods likely to harm the environment. Article 4, see Annex III.

D 1 Deposit into or onto land (e.g. landfill, etc.)

D 2 Land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.)

D 3 Deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.)

D 4 Surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.)

D 5 Specially engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)

D 6 Release into a water body except seas/oceans

D 7 Release into seas/oceans including sea-bed insertion

D 8 Biological treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D 1 to D 12

D 9 Physico-chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D 1 to D 12 (e.g. evaporation, drying, calcination, etc.)

D 10 Incineration on land

D 11 Incineration at sea

D 12 Permanent storage (e.g. emplacement of containers in a mine, etc.)

D 13 Blending or mixing prior to submission to any of the operations numbered D 1 to D 12

D 14 Repackaging prior to submission to any of the operations numbered D 1 to D 13

D 15 Storage pending any of the operations numbered D 1 to D 14 (excluding temporary storage, pending collection, on the site where it is produced)

ANNEX III

RECOVERY OPERATIONS (96/350/EC: Commission Decision of 24 May 1996 adapting Annexes IIA and IIB to Council Directive 75/442/EEC on waste, Annex IIB)

NB: This Annex is intended to list recovery operations as they occur in practice. In accordance with Article 4 (directive 91/156/EC) waste must be recovered without endangering human health and without the use of processes or methods likely to harm the environment.

R 1 Use principally as a fuel or other means to generate energy

R 2 Solvent reclamation/regeneration

R 3 Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)

R 4 Recycling/reclamation of metals and metal compounds

R 5 Recycling/reclamation of other inorganic materials

R 6 Regeneration of acids or bases

R 7 Recovery of components used for pollution abatement

R 8 Recovery of components from catalysts

R 9 Oil re-refining or other reuses of oil

R 10 Land treatment resulting in benefit to agriculture or ecological improvement

R 11 Use of wastes obtained from any of the operations numbered R 1 to R 10

R 12 Exchange of wastes for submission to any of the operations numbered R 1 to R 11

R 13 Storage of wastes pending any of the operations numbered R 1 to R 12 (excluding temporary storage, pending collection, on the site where it is produced)

Article 4 Directive 91/156/EC

Member States shall take the necessary measures to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular:

- without risk to water, air, soil and plants and animals,
- without causing a nuisance through noise or odours,
- without adversely affecting the countryside or places of special interest.

Member States shall also take the necessary measures to prohibit the abandonment, dumping or uncontrolled disposal of waste.

Annex IV

Materials and components exempt from Article 4(2)(a) (2002/525/EC: Commission Decision of 27 June 2002 amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles, Annex II)

Lead as an alloying element

1. Steel for machining purposes and galvanized steel containing up to 0,35 % lead by weight

2. a) Aluminium for machining purposes with a lead content up to 2 % by weight 1 July 2005 (1)

   b) Aluminium for machining purposes with a lead content up to 1 % by weight 1 July 2008 (2)

3.Copper alloy containing up to 4 % lead by weight

4. Lead-bronze bearing shells and bushes

Lead and lead compounds in components

5. Batteries (X)

6. Vibration dampers (X)

7. Wheel balance weights. Vehicles type-approved before 1 July 2003 and wheel balance weights intended for servicing of these vehicles: 1 July 2005 (3) (X)

8. Vulcanising agents and stabilisers for elastomers in fluid handling and powertrain applications 1 July 2005 (4)

9. Stabiliser in protective paints 1 July 2005

10. Carbon brushes for electric motors. Vehicles type-approved before 1 July 2003 and carbon brushes for electric motors intended for servicing of these vehicles: 1 January 2005

11. Solder in electronic circuit boards and other electric applications (X) (5)

12. Copper in brake linings containing more than 0,5 % lead by weight. Vehicles type-approved before 1 July 2003 and servicing on these vehicles: 1 July 2004 (X)

13. Valve seats. Engine types developed before 1 July 2003: 1 July 2006

14. Electrical components which contain lead in a glass or ceramic matrix compound except glass in bulbs and glaze of spark plugs (X) (6) (for components other than piezo in engines)

15. Glass in bulbs and glaze of spark plugs 1 January 2005

16. Pyrotechnic initiators 1 July 2007

Hexavalent chromium

17. Corrosion preventive coatings 1 July 2007

18. Absorption refrigerators in motorcaravans (X)

Mercury

19. Discharge lamps and instrument panel displays (X)

Cadmium

20. Thick film pastes 1 July 2006

21. Batteries for electrical vehicles After 31 December 2005, the placing on the market of NiCd batteries shall only be allowed as replacement parts for vehicles put on the market before this date.

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(1) By 1 January 2005 the Commission shall assess whether the phase-out time scheduled for this entry has to be reviewed in relation to the availability of substitutes for lead, taking into account the objectives of Article 4(2)(a).

(2) See footnote 1.

(3) By 1 January 2005, the Commission shall assess this exemption in relation to road safety aspects.

(4) See footnote 1.

(5) Dismantling if, in correlation with entry 14, an average threshold of 60 grams per vehicle is exceeded. For the application of this clause, electronic devices not installed by the manufacturer on the production line shall not be taken into account.

(6) Dismantling if, in correlation with entry 11, an average threshold of 60 grams per vehicle is exceeded. For the application of this clause, electronic devices not installed by the manufacturer on the production line shall not be taken into account.

in accordance with Article 4(2)(b)(iv)

Notes:

— a maximum concentration value up to 0,1 % by weight and per homogeneous material, for lead, hexavalent chromium and mercury and up to 0,01 % by weight per homogeneous material for cadmium shall be tolerated, provided these substances are not intentionally introduced (1),

— a maximum concentration value up to 0,4 % by weight of lead in aluminium shall also be tolerated provided it is not intentionally introduced (2),

— a maximum concentration value up to 0,4 % by weight of lead in copper intended for friction materials in brake linings shall be tolerated until 1 July 2007 provided it is not intentionally introduced (3),

— the reuse of parts of vehicles which were already on the market at the date of expiry of an exemption is allowed without limitation since it is not covered by Article 4(2)(a), until 1 July 2007, new replacement parts intended for repair (4) of parts of vehicles exempted from the provisions of Article 4(2)(a) shall also benefit from the same exemptions.'

(1) "Intentionally introduced" shall mean "deliberately utilised in the formulation of a material or component where its continued presence is desired in the final product to provide a specific characteristic, appearance or quality". The use of recycled materials as feedstock for the manufacture of new products, where some portion of the recycled materials may contain amounts of regulated metals, is not to be considered as intentionally introduced.

(2) See footnote 1.

(3) See footnote 1.

(4) This clause applies to replacement parts and not to components intended for normal servicing of vehicles. It does not apply to

wheel balance weights, carbon brushes for electric motors and brake linings as these components are covered in specific entries.

ANNEX V

Minimum technical requirements for treatment (Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, AnnexI)

1. Sites for storage (including temporary storage) of end-of-life vehicles prior to their treatament:
- impermeable surfaces for appropriate areas with the provision of spillage collection facilities, decanters and cleanser-degeasers,
- equipment for the treatment of water, including rainwater, in compliance with health and environmental regulations.
2. Sites for treatment:
- impermeable surfaces for appropriate areas with the provision of spillage collection facilities, decanters and cleanser-degreasers,
- appropriate storage for dismantled spare parts, including impermeable storage for oil-contaminated spare parts,
- appropriate containers for storage of batteries (with electrolyte neutralisation on site or elsewhere), filters and PCB/PCT-containing condensers,
- appropriate storage tanks for the segregated storage of end-of-life vehicle fluids: fuel, motor oil, gearbox oil, transmission oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, battery acids, air-conditioning system fluids and any other fluid contained in the end-of-life vehicle,
- equipment for the treatment of water, including rainwater, in compliance with health and environmental regulations,
- appropriate storage for used tyres, including the prevention of fire hazards and excessive stockpiling.
3. Treatment operations for depollution of end-of-life vehicles:
- removal of batteries and liquified gas tanks,
- removal or neutralisation of potential explosive components, (e.g. air bags),
- removal and separate collection and storage of fuel, motor oil, transmission oil, gearbox oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, air-conditioning system fluids and any other fluid contained in the end-of-life vehicle, unless they are necessary for the re-use of the parts concerned,
- removal, as far as feasible, of all components identified as containing mercury.
4. Treatment operations in order to promote recycling:
- removal or catalysts,
- removal of metal components containing copper, aluminium and magnesium if these metals are not segregated in the shredding process,
- removal of tyres and large plastic components (bumpers, dashboard, fluid containers, etc), if these materials are not segregated in the shredding process in such a way that they can be effectively recycled as materials,
- removal of glass.
5. Storage operations are to be carried out avoiding damage to components containing fluids or to recoverable components and spare parts.

Annex VI

A table of European Community (EC) law and related Swedish law.

The table shows European Community laws and in the row below related Swedish laws, for example the EC Waste directive 75/442/EC is implemented in Sweden by SFS 1998:808, SFS 2001:1063 and SFS 1998:653.

E C Waste	Directive 75/442/EC. Amendments 91/156/EEC and 91/692 EEC.
Swedish laws	SFS 1998:808, SFS 2001:1063 and SFS 1998:653
EC Landfill of waste	Directive 1999/31/EC
Swedish laws	SFS 1998:808, SFS 2001:512, SFS 2001:1063, SFS 1998:901, NFS 2001:14 and NFS 2002:33.
EC Hazardous waste	Directive 91/689/EEC. Amendment Directive 94/31/EEC.
Swedish laws	SFS 1998:808, SFS 2001:1063, SFS 1982:821, SFS 1982:923, SFS 1994:2035, SOSFS 1999:27 (M) and SOSFS 2000:4 (M)
EC Waste transports	93/253/EEC. Amendments 97/120 (97/120R), 2001/2557.
Swedish laws	93/253/EEC. Amendments 97/120 (97/120R), 2001/2557. SFS 1998:808, SFS 1995:701, NFS 2001:14, NFS 2002:33.
EC Waste oils	Directive 75/439/EEC. Amendments 87/101/EEC, 91/692/EEC, 2000/76/EC.
Swedish laws	SFS 1998:808, SFS 1993:1268, SFS 2001:1063.
EC ELV	Directive 2000/53/EC. Amendment 2002/525/EC.
Swedish laws	SFS 1998:808, SFS 1998:899, SFS 1975:343, SFS 1975:348, SFS 2003:208, SFS 1997:788, SFS 1997:788, SFS 2001:559, SFS 2002:925, SFS 1972:599, SFS 2001:650 and NFS 2002:2.
EC Batteries and accumulators	Directive 91/157/EEC. Amendments 98/101/EC and 93/86/EEC.
Swedish related laws	SFS 1998:808, SFS 1997:645 and SFS 1990:1332.

Annex VII

Abbreviations

Cd:	Cadmium
CrVI:	Hexavalent chromium
EEE:	Electrical and electronic equipment
ELV:	End-of-life vehicle
Hg:	Mercury
NFS:	Naturvårdsverkets föreskrifter (Regulations of the Swedish Environmental Protection Agency)
Pb:	Lead
SFS:	Svensk FörfattningsSamling (Swedish Code of Statutes)
SOSFS:	Socialstyrelsens föreskrifter och allmänna råd (Regulations and Common Advice of the Swedish National Board of Health and Welfare)
WEEE:	Waste electrical and electronic equipment

Annex VIII

Definitions

Biodegradable waste: Any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard.

Co-incineration plant: Any stationary or mobile plant whose main purpose is the generation of energy or production of material products and:
- which uses wastes as a regular or additional fuel; or
- in which waste is thermally treated for the purpose of disposal.

If co-incineration takes place in such a way that the main purpose of the plant is not the generation of energy or production of material products but rather the thermal treatment of waste, the plant shall be regarded as an incineration plant within the meaning of Incineration plant. This definition covers the site and the entire plant including all co-incineration lines, waste reception, storage, on site pre-treatment facilities, waste-, fuel- and air-supply systems, boiler, facilities for the treatment of exhaust gases, on-site facilities for treatment or storage of residues and waste water, stack devices and systems for controlling incineration operations, recording and monitoring incineration conditions.

Collection: The gathering, sorting and/or mixing of waste for the purpose of transport.

Disposal: Any of the operations provided for in Annex II, A to the European Directive on waste (96/350/EC: Commission Decision of 24 May 1996 adapting Annexes IIA and IIB to Council Directive 75/442/EEC on waste), see Annex II in this report.

Electrical and electronic equipment (EEE): Equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex IA (not included in this report) to the European WEEE Directive (2002/96/EC) and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current

End-of life vehicle: A vehicle which is waste. See definition of waste.

Hazardous waste: Waste categories are listed in the European ELV Directive (2000/532/EC) (not included in this report).

Incineration plant: Any stationary or mobile technical unit and equipment dedicated to the thermal treatment of wastes with or without recovery of the combustion heat generated. This includes the incineration by oxidation of waste as well as other thermal treatment processes such as pyrolysis, gasification or plasma processes in so far as the substances resulting from the treatment are subsequently incinerated.
This definition covers the site and the entire incineration plant including all incineration lines, waste reception, storage, on site pretreatment facilities, waste-fuel and air-supply systems, boiler, facilities for the treatment of exhaust gases, on-site facilities for treatment or storage of residues and waste water, stack, devices and systems for controlling incineration operations, recording and monitoring incineration conditions.

Inert waste: Waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater.

Landfill: A waste disposal site for the deposit of the waste onto or into land (i.e. underground), including:
- internal waste disposal sites (i.e. landfill where a producer of waste is carrying out its own waste disposal at the place of production), and
- a permanent site (i.e. more than one year) which is used for temporary storage of waste,
but excluding:
- facilities where waste is unloaded in order to permit its preparation for further transport for recovery, treatment or disposal elsewhere, and
- storage of waste prior to recovery or treatment for a period less than three years as a general rule, or
- storage of waste prior to disposal for a period less than one year.

Mixed municipal waste: Waste from households as well as commercial, industrial and institutional waste, which because of its nature and composition is similar to waste from households, but excluding fractions indicated in the Annex to Decision 94/3/EC(22) under heading 20 01 that are collected separately at source and excluding the other wastes indicated under heading 20 02 of that Annex (not included in this report).

Municipal waste: Waste from households, as well as other waste which, because of its nature or composition, is similar to waste from household.

Non-hazardous waste: Waste categories are listed in the ELV Directive (2000/532/EC) (not included in this report).

Recovery: any of the operations provided for in Annex II, B the European Directive on waste (96/350/EC: Commission Decision of 24 May 1996 adapting Annexes IIA and IIB to Council Directive 75/442/EEC on waste) see Annex III in this report.

Recycling[2]: The reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. Energy recovery means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat.

Regeneration: Any process whereby base oils can be produced by refining waste oils, in particular by removing the contaminants, oxidation products and additives contained in such oils.

Reuse: Any operation by which components of end-of life vehicles are used for the same purpose for which they were conceived.

Waste: Any substance or object in the categories set out in Annex I (see Annex I in this report), which the holder discards or intends or is required to discard. Waste categories are listed in the ELV Directive (2000/532/EC) (not included in this report).

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[2] The definition of Recycling have been an issue for the Court of Justice of the European Communities. JUDGMENT OF THE COURT (Fifth Chamber) 19 June 2003. (Directive 75/442/EEC, as amended by Directive 91/156/EEC and Decision 96/350/EC - Directive 94/62/EC - Concept of waste - Concept of recycling -Processing of metal packaging waste). In Case C-444/00.
Recycling within the meaning of Article 3(7) of European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste is to be interpreted as not including the reprocessing of metal packaging waste when it is transformed into a secondary raw material such as material meeting the specifications of Grade 3B, but as covering the reprocessing of such waste when it is used to produce ingots, sheets or coils of steel. That interpretation would be no different if the concepts of recycling and waste referred to by Council Directive 75/442/EEC of 15 July 1975 on waste were taken into account.

Annex IX

Swedish Reports regarding Producer responsibility

This Annex contains summaries from some Swedish Governmental reports that could be of interest from a recycling/waste management point of view.

Ett ekologiskt hållbart omhändertagande av avfall (Ecologically sustainable waste management) by The Swedish Environmental Protection Agency (Report 5177, 2002)

The report states that the overall aim of environmental protection is to ensure that we leave the next generation a society in which the main environmental problems have been solved. This requires us to reduce impacts on the environment to sustainable levels. The report is confined to the categories of waste covered by the ban on landfilling burnable and organic waste. The main categories included are: household waste, construction and demolition waste and non-sector-specific industrial waste. Sector-specific industrial waste is included insofar as it falls within the landfill bans.

Current waste management wastes resources. Materials and energy are not put to the best use; waste that could be recycled is still being landfilled. Degradable waste that is landfilled gives rise to methane emissions. These represent approximately 3 per cent of total Swedish greenhouse gas emissions. Incineration of plastic and waste transport (particularly refuse collection), gives rise to emissions of carbon dioxide of fossil origin. Present emissions of hazardous substances from management of the types of waste included in this report are relatively small in comparison with other sources. However, there is an element of doubt and we do not know enough about the long-term effects of emissions from landfill in particular, including landfill of ash from waste incineration. The same also applies to recycling (including composting and digestion) of waste that may contain low concentrations of hazardous substances.

In outline, efforts to achieve ecologically sustainable waste management on the basis of the environmental quality objectives, taking account of the environmental impact of waste management, may proceed in line with the following guidelines.

- Reduced hazard and reduced quantities of waste by means of preventive action.

- Detoxification of the ecocycle. It should be ensured that hazardous substances do not escape into the environment or the ecocycle as a result of poor control of recycling or incorrect disposal. Waste containing hazardous substances should be sorted and handled separately for recycling, destruction or, if destruction is not possible, long-term safe storage.

- Long-term low emissions from waste management. All forms of waste management should be conducted so that, in both the short and the long term, they do not generate emissions posing a risk to human health or the environment.

- Resource management. The resource that waste represents in the form of materials or energy must be utilised to the maximum possible extent and with the greatest possible degree of refinement. This will make it possible to effectively use both renewable and finite resources so as to reduce the environmental impact caused by products throughout their life-cycle, and will also help to create sustainable production systems.

The Swedish Government has instructed the Swedish Environmental Protection Agency to ascertain whether there is a need to introduce new instruments to achieve the overall objectives of waste management. The Swedish Government considers it to be of particular interest to examine instruments that encourage a balanced use of methods for recycling, biological treatment and energy utilization.

On the basis of the guidelines mentioned above and an assessment of the environmental impact of waste management, among other things, the authors have drawn the following conclusions about the types of waste included in the report.

- From an environmental viewpoint, landfill is the least preferable way of disposing of waste that could be recycled or incinerated. Whether incineration combined with energy extraction or recycling is chosen, the environmental impact of waste management is reduced as compared with landfill.

- From an environmental point of view, incineration, biological treatment and other recycling methods are acceptable, provided that waste quality standards are set and adequate precautionary measures in the form of effective treatment equipment etc are in place. However, we need to know more about fugitive dispersal of hazardous substances so that further measures can be taken if necessary.

- Recycling has advantages over incineration, since it is thereby possible to create waste management systems involving virtually no landfilling, in which material and nutrients form part of an ecocycle. This often reduces energy consumption and environmental impact. Recycling has the added advantage of providing valuable feedback for product development so that those manufacturing a given product are made aware of its environmental impacts.

- At present, recycling is often more expensive and labour-intensive than incineration. We consider that achievement of an environmentally well-balanced combination of incineration and recycling will require further instruments to strengthen the incentives for recycling where this is justified on environmental grounds.

- Direct action will be necessary if waste management is to become more environmentally compatible. This will involve sorting, technical preventive measures, information etc, as well as administrative instruments such as good planning, clear division of responsibilities, effective monitoring of achievement, reliable statistics and research and development.

It is proposed that the landfill tax be raised by SEK 50/tonne on 1 January 2003, 2004 and 2005 for waste qualifying for exemption from the ban on landfilling burnable and organic waste.

Forecasts indicate that the ban on landfilling burnable waste will have been largely implemented some time during 2004 to 2006. There is an element of uncertainty depending on whether and by how much waste quantities will increase, as well as the extent of plans for additional incineration and biological treatment capacity, and the rate at which they are realised. In addition, the competitive relationship between Swedish and imported waste fuels may also affect the rate.

Applications to county administrative boards for exemption from the ban on landfilling combustible waste will hasten decisions to increase treatment capacity and ensure that these decisions are in fact taken. If the landfill tax on waste qualifying for exemption is progressively raised, as proposed in this report, this will further accelerate the reduction in landfill.

EU-prioriteringar för att nå miljömålen (EU priorities to achieve the environmental objectives) by The Swedish Environmental Protection Agency(Report 5250, 2002).

Part of the summary conclusions:
The European Commission's Environment Directorate-General has begun working on thematic strategies, which will be developed over the next few years, and which will constitute core policy development in the environmental field. Sweden should adopt a pro-active stance by contributing background material for the strategies considered to have the greatest impact on Swedish environmental quality objectives, and should offer to take an active part in the Environment DG's development of thematic strategies, primarily in relation to protecting the marine environment, air quality, sustainable pesticide use, sustainable use of resources and recycling. It requires considerably more effort for a country to put an entirely new issue on the agenda and achieve results, than to influence proposals already being developed. However new Swedish initiatives may also be needed. The report also includes information about different European countries prioritized areas regarding Environmental issues.

Samla in, återvinn! (Collect, Recycle!) by The Swedish Environmental Protection Agency (Report 5237, 2002)

In the summary states that the Producer responsibility is constantly being extended. The majority of all recovery targets for different product groups are being met or exceeded. All collected tyres are disposed of in other ways than landfilling. Recycling and material substitution (for example cut used tyres are used as a road material in deposits) have increased substantly during 2001 from 30.6 % to 54.9 % and are now the dominant treatment methods. The ELV recovery rate for 2001 is 81%, for lead batteries the recycling rate is 95%. Collection of WEEE is 10kg per inhibitant and year. The repost also include a discussion about future recycling of vehicles and changes in the Swedish legislation regarding recycling of ELV.

Appendix B

Trends in society concerning waste treatment and producer responsibility

Introduction

This study of trends in society concerning legislation on the field of waste handling and recycling has been carried out during December 2003 through February 2004. The purpose was to map out the environmental objectives in Sweden and in the European Union, and see in which way these objectives may have an influence on waste legislation. Also, another purpose of the study was to map out other areas of discussion within the European Union that may alter the legislation in the field of wastes and recycling thus affecting producers.

This report states the Swedish Environmental Objectives, the four priority areas for urgent action within the Sixth Environment Action Programme of the European Community, the seven thematic strategies within the 6th EAP, and lists some other areas that are discussed. The results of the study are that no major changes in legislation can be expected for the automotive industry, where the ELV Directive is the most important steering document. For other industries, however, there may be changes. The most important process concerning the issue is the thematic strategy for material recycling and waste prevention.

Environmental objectives

Sweden

The 15 Swedish national environmental objectives are the following:

1. Reduced Climate Impact
2. Clean Air
3. Natural Acidification Only
4. A Non-Toxic Environment
5. A Protective Ozone Layer
6. A Safe Radiation Environment
7. Zero Eutrophication
8. Flourishing Lakes and Streams
9. Good-Quality Groundwater
10. A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
11. Thriving Wetlands
12. Sustainable Forests
13. A Varied Agricultural Landscape
14. A Magnificent Mountain Landscape
15. A Good Built Environment

There is no environmental quality objective that is directly linked to the waste issue. In "Ett ekologiskt hållbart omhändertagande av avfall", links between waste and natural resources and the following objectives are mapped out:

- A Good Built Environment
    - Deals with waste treatment, landfills etc
- Reduced Climate Impact
    - Deals with methane from composts, and CO2 from incineration of wastes
- A Non-Toxic Environment
    - Deals with hazardous wastes

According to Erik Westin at the Swedish EPA there are no plans to develop a Swedish environmental objective for issues concerning natural resources and waste.

In "Nationell strategi för hållbar utveckling" [2001/02:172], waste and recycling issues are not addressed directly. However, for a sustainable development, it is stated that a sustainable use of natural resources will be necessary.

The proposal "Ett samhälle med giftfria och resurssnåla kretslopp" which has been delivered to the Swedish parliament 2003-05-15, [Regeringens proposition 2002/03:117], mentions the responsibility of producers and consum ers in the area of waste prevention. However, no detailed information on suggestions for extended producer responsibilities was included.

Within the Ministry of Environment, issues concerning waste and producer responsibility are highly connected to resource issues. A reference is also made to the environmental product politics, the Swedish correspondence to IPP.

European Union

Four priority areas for urgent action have been issued within Sixth Environment Action Programme of the European Community. The priority areas are:

- Climate Change
- Nature and Biodiversity
- Environment and Health and quality of life
- Natural Resources and Waste

Within the Sixth EAP, seven thematic strategies have been mapped out:

- Clean Air For Europe (CAFE)
- Soil protection
- Sustainable use of pesticides
- Protect and conserve the marine environment
- <u>Waste prevention and recycling</u>
- <u>Sustainable use of natural resources</u>
- Urban environment

The waste prevention and recycling as well as the sustainable use of natural resources can be seen as the most important of these strategies that concern Design for Recycling.

Thematic strategy on waste prevention and recycling
New strategy on materials recycling and prevention of waste generation from European Commission. May 2003, communication on the development of this strategy.

The communication invites to a broad discussion concerning the following questions:

? Identifying potentials for waste prevention;
? Exchange of good practices and experience with a view to defining how the EU may contribute to these;
? The role of the future chemicals policy as regards qualitative prevention of waste;
? Exploring how voluntary or mandatory waste prevention plans could contribute to waste prevention;
? Assessing the waste prevention potential of the directive on Integrated Pollution prevention and Control (IPPC).

Options to promote recycling mentioned in the strategy, are:

? The development of material based recycling targets in articulation with end-of-life products based targets;
? Getting the prices of the different waste treatment options right by using economic instruments, which could include tradable certificates, the co-ordination of national landfill taxes, promoting pay-as-you-throw schemes and making producers responsible for recycling;
? Ensuring recycling is both easy and clean. In some cases, implementation of EU waste law may have led to unnecessary burdens on the recycling industry. Such problems need to be identified and solved. Additionally, common approaches for recycling could ensure that recycling businesses apply the best available technology.

Communication Towards a Thematic Strategy on the Sustainable Use of Natural Resources

This thematic strategy strives for decoupling consumption from economic growth. The main principle of this strategy is to use less/fewer resources per unit of GDP, and

? to maintain availability of resources
? to reduce the environmental impact of development, use and disposal of resources
? mapping the links between use of resources and their environmental impacts to identify where action is needed.

The goal affects many parts of society and demands for large changes, so the time scale for its implementation has been set to 25 years. At the time being, the environmental effects from using resources are seen to be larger than the resource depletion itself. The Thematic strategy on waste prevention and materials recycling should be seen as lying underneath or as a part of this thematic strategy.

Both thematic strategies are to be developed during 2004.

Integration of Swedish and European interests

Priority environmental areas (in EU):
"Resources and waste. The Commission will be developing thematic strategies for resources and waste. A large number of new directives and programmes governing waste and use of resources can be expected in the Commission's working plan for the next year; some of these may be delayed owing to the current focus on thematic strategies. Legislation on resources and waste will ultimately have a major impact on the design and content of various products, which will have an impact particularly on the prospects of achieving the *Non-toxic environment* objective, and also on *A good built environment.* Sweden should develop its own strategy for what it wants to achieve in the waste and resources field in the EU, and should also take an active part in Commission work, eg, by proposing that a Swedish national expert work there." [EU-related priorities to achieve the 15 Swedish environmental objectives]

Other areas of discussion that may affect future requirements

The following areas of European Environmental legislation/research may have influence on the handling of wastes in the future:

IPP
The Integrated Product Policy addresses the issue of taking the environmental aspects of the whole life-cycle of a product into consideration, which includes the end-of-life phase. It may influence future requirements for recycling. The IPP discussions may well lead to altered requirements for recycling, as well as a requirement for a more holistic viewpoint for producers.

Is seen as the toolbox for the two thematic strategies mentioned above.

REACH
The new legislation for chemicals may affect recycling. If the new chemicals legislation prohibits certain chemical substances as trace elements in production of new products, this may make it more difficult to find markets for recycled goods.

End-of-life Directive for Heavy Duty Vehicles and/or other products
Any extension of the producer responsibility to encompass other products than those which already are included is not planned at the moment. The Directorate-Géneral Environment refers to the ongoing activities with the thematic strategy for materials recycling and prevention of waste, please see page 3 above for more information.

Conclusions and recommendations

There is a high focus on resource and waste issues today, which can be seen in documents and activities carried out by the Swedish and European authorities. However, it can not be seen clearly that higher demands on producers may be expected in the future, apart from the End-of-life Directive for passenger vehicles that exists today. The European Commission does neither confirm or deny that there will be an extended producer responsibility for other products than passenger vehicles. However, the work with the Thematic strategy on waste prevention and recycling is emphasized. The thematic strategy may give way for more stringent legislation in the future.

Recommendations for future scenarios will be "state-of-the-art" for producer responsibility for passenger vehicles but with slightly higher demands on material recycling (targets based on material contents). The thematic strategy includes economic incentives for waste prevention and materials recycling, which may imply changes in the production and consumption patterns without legal requirements.

References

http://www.europa.eu.int/comm/environment/waste/strategy.htm
http://miljo.regeringen.se
http://www.environ.se

Swedish EPA, Ett ekologiskt hållbart omhändertagande av avfall, February 2002, Report no. 5177

Swedish EPA, EU-related priorities to achieve the fifteen Swedish environmental objectives, Summary conclusions, 2002, Dnr 126-1918-02 U

GPC Policy paper on EU Strategies on natural Resources, Waste & integrated Product Policy, Common Treads and Implications, ACEA End of life vehicles No. 596, January 5th 2004

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Appendix C

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End of Life Vehicle treatment

Abstract

This report gives an overview of the different technologies that can be used for treating End of Life Vehicles (ELV's) and the materials from them. It covers the technologies used today but also technologies possible for the future. The work has been carried out as a part in the Design for Recycling project initiated by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material systems) in the end of 2002.

The ELV treatment can be described as a 4-step-process. The first step is the pre-treatment of the ELV's, when harmful substances are removed from the vehicles. This step includes for example draining of the different fluids, neutralization of pyrotechnical devices and dismantling of the battery.
The second step is the dismantling of parts. Traditionally, parts that can be re-used are dismantled. Parts can also be dismantled and sent to recycling. Next step, the third, is shredding. The ELV's are shreddered in a hammer mill followed by sorting and separation of different metal fractions which are recycled. The last and fourth step is the shredder residue treatment. The shreddered materials remaining after the metals are sorted out can be treated further, either to recyclable or recoverable fractions. A minimal fraction is to be left for disposal.

To fulfil the recovery and recycling quotas set up in the ELV directive (2000/53/EC), more materials from the ELV's have to be recycled and recovered in the future. There are two different ways to achieve this, either to extend the dismantling of parts or to use some of the post-shredder treatment technologies (PST's). As the dismantling is costly, the focus at the moment is on evaluating the available PST's from economical, technical and environmental point of views.

The prerequisites, such as the amount of ELV's to be treated and the market for the fractions/materials that are sorted out for recovery or recycling as well as national/regional regulations on waste handling, differ largely from one country to another, sometimes even within the same country. Probably, there will be national, or sometimes even regional, solutions to what to do to fulfil the recovery and recycling quotas.

Acronyms, abbreviations and definitions

ASR	Automotive Shredder Residues
CPM	Chalmers Competence Center in Environmental Assessment of Product and Material Systems
ELV	End of Life Vehicle
ELV directive	End-of-Life-Vehicle Directive, 2000/53/EC
OEM	Original Equipment Manufacturer
Recoverability rate	Percentage by mass of a *new* vehicle that can potentially be recovered, reused or both
Recovery	Reprocessing, in a production process, of the waste materials for the original purpose or for other purposes, and the processing as means of generating energy
Recyclability rate	Percentage by mass of a *new* vehicle that can potentially be recycled, reused or both
Recycling	Reprocessing, in a production process, of the waste materials for the original purpose or for other purposes, excluding the processing as means of generating energy
SFS 1997:788	Swedish Ordinance on Producer responsibilitiy for vehicles
SR	Shredder Residues
PST	Post Shredder Treatment

Contents

1. Introduction

Background
This report is a part of the Design for Recycling project initiated by CPM. It shall give an overview of the different technologies that can be used for treating End of Life Vehicles (ELV's) and the materials from them, both the technologies used today and also technologies possible for the future.

The main driving force for recovery and recycling of the ELV's is the End-of-Life-Vehicle Directive 2000/53/EC. This directive set up recovery and recycling quotas to be reached.

Purpose
The purpose of this report is to describe the system for ELV treatment and to give an overview of the different technologies that can be used for treating ELV's and the materials from them.

Objectives
The first objective is to give very brief descriptions of different recycling technologies adding references to reports, books etc describing these technologies more in detail. The second objective is to list as many relevant market actors as possible.

Scope
This report mainly covers technologies used, or under development, in Sweden and Europe. Some information about similarities or differences looking at the situations in America and Japan is also included.

2. Methodology

The base for this report is information gathered at Saab Automobile from conferences, by visiting companies and by reading reports and published material (including websites).

3. Results

3.1 ELV directive and Swedish Producer responsibility for vehicles

The ELV directive 2000/53/EC was published in the autumn of 2000. The directive contains targets for how much of the materials from the ELV's that has to be re-used, recovered and/or recycled. In 2006, at the minimum 85% of the vehicle weight shall be recovered or re-used and at the minimum 80% of the vehicle weight shall be recycled or re-used. For 2015, the targets are 95% respectively 85%. These quotas correspond to the real life ELV treatment and they are tracked in so called monitoring. Every member state in EU has to establish a monitoring system where the amount of materials for re-use, recovery and recycling are tracked and reported. These systems can be more or less complicated and also the extent of administration varies.
The re-use, recycling and recovery quotas for 2015 will be reviewed, at the latest, on the 31st of December 2005, based on a report from the EU Commission. This report shall deal with the development regarding material content in vehicles and also other relevant environmental aspects related to vehicles.

The ELV directive also includes requirements on the recoverability and recyclability rate of new vehicles to be type approved. This is about how much of the new vehicle that can *potentially* be recovered, re-used or both respectively recycled, re-used or both.There is an ISO standard 22628 Road vehicles – Recyclability and recoverability – Calculation method established for this purpose. This is a theoretical calculation method and cannot reflect the process that will be applied to the vehicle at the end of its life time – the life time of a passenger car can be up to 20-30 years and it is impossible to predict the exact technologies to be used in such big advance. At present time, it is not yet settled when this recoverability and recyclability calculation will be included in the type approval process for the vehicles, but at the earliest, this will happen in the middle of 2005. The requirements for these new cars are a recoverability rate of 95% (of the vehicle weight) and a recyclability rate of 85% (of the vehicle weight).

From the 1st of July 2003, the ELV directive ban the use of the four heavy metals lead, mercury, cadmium and hexavalent chromium. Some exceptions from this ban are stated in the AnnexII to the directive. The AnnexII will be revised from time to time.
The ELV directive contains several other things e.g. some wordings about economic responsibility, requirements on proper pre-treatment (real life) and that dismantling information for the vehicles has to be established.

In Sweden, we have had a Producer responsibility for vehicles (SFS 1997:788) since 1998. It includes the recovery quotas (including re-use) of 85% per 2002 and 95% per 2015. There are no recycling quotas.

3.2 ELV treatment

3.2.1 ELV treatment 4-step-process

The ELV treatment can be described as a 4-step-process. The 4 steps are pre-treatment, dismantling, shredding and shredder residue treatment.

3.2.1.1 Pre-treatment

The first step is the pre-treatment of the ELV's, when harmful substances are removed from the vehicles. This step includes for example draining of the different fluids, neutralization of pyrotechnical devices and dismantling of the battery.

3.2.1.2 Dismantling

The second step is the dismantling of parts. Traditionally, parts that can be re-used, either directly or after being reconditioned, are dismantled. Parts can also be dismantled and sent for recycling. The dismantled parts would be sorted by the dismantler into different bins containing defined fractions to be sent to some recyclers. The parts could either be sent whole and unbroken or they could be fragmentized in a smaller shredder at the dismantler's site to reduce the volumes and make the logistics more economically feasible. What fractions to be sorted and what contaminations are accepted are decided by the recyclers mainly.

Some recyclers offer their recycled material on an open market, others are fully contracted for supplying their recycled material.

Dismantling of valuable **metals** is of interest when the dismantler gets paid more money for the sorted metals than the money he/she spends on dismantling. Today, metals are dismantled only in exceptional cases as the infrastructure for recycling metals after shredding is established and economically feasible since years.

Glass is dismantled at the Swedish dismantlers since 2002, more information about this is found in 3.3.2.5.

Polymeric parts has been dismantled and recycled in a number of different studies but there is no commercial recycling of polymers from ELV's today because of an uneconomic situation.

3.2.1.3 Shredding

The third step is shredding. The ELV's are shreddered in a hammer mill followed by sorting and separation of different metal fractions which are sent for recycling directly or for further separation before the metal is recycled. The report Shredder technology development and trends in Europe[1] describes the shredding more in detail.

A shredder plant often treats different sources of scrap such as white goods, industrial scrap and ELV's. It is not very common that ELV's are treated separately, which after metal separation leave an Automotive Shredder Residue (ASR). Instead, the different sources of scrap are mixed in certain proportions to attain a desired metal content to be sorted out and the other materials end up in the Shredder Residue (SR).

3.2.1.4 Shredder residue treatment

The last and fourth step is the shredder residue treatment. The shreddered materials remaining after the metals are sorted out can be treated further, either to recyclable or recoverable fractions. There are a number of technologies for treating the SR. Several reports are available[2,3,4].
A minimal fraction is to be left for disposal.

3.2.2 Options to increase the recovery and recycling quotas of ELV's

In the very beginning of the discussions about how to increase the recovery and recycling quotas from the ELV's, the main focus was on extending the dismantling of parts. The advantages of the dismantling route are low investments and that you receive rather big parts containing identified, and to a limited number of, materials. The big disadvantage is that manual dismantling is costly.

There has been many studies[5,6] performed on this topic. In the ECRIS[6] project, dismantling times for a number of parts and vehicles were recorded. Also some theoretical studies on the economics of dismantling and recycling are carried out[5,7]. Conclusions from the report Dismantling[5] are that some technical problems exist regarding the quality of sorting and separation and the labour cost for dismantling components is high. The author to the paper Disassembly modeling used to assess automotive recycling opportunities[7], concludes that recycling of non-metals via traditional dismantling procedures (i.e. disassembly) will not be economically feasible despite attempts at Design for Recycling or changes in the marketplace.

The option to dismantling is introducing shredder residue treatment. As the extended dismantling is an expensive way to increase the recycling quota, the automotive industry is now focused on evaluating the post shredder technologies from economical, technical and environmental point of views. One thing not clear yet, is the official acceptance of respective technology as recycling or recovery. This will also influence the choice of technologies to be used as there are not only recovery quotas but also recycling quotas to be fulfilled.

The materials in a vehicle can, very roughly, be divided into the material categories metals (70-80% of the weight of the car), polymers (10-20%) , glass (< 5%) and others (< 5%). The metals are recycled since years and next big material category is the polymers.
Polymeric materials can be recycled in different ways. One category of processes is the mechanical recycling when the molecules in the polymer material are kept without any modifications. The traditional regrinding and remelting of thermoplastics belong to this category and so do the selective dissolution processes also (selective dissolution process is described in 3.4.2.4, see Vinyloop). Another category is chemical recycling where the molecules are broken down to smaller building blocks which can be used to build new materials. The chemical recycling processes includes some kind of a chemical agent which is adapted to the material to be depolymerized. A third category is the feedstock recycling by thermolysis where the organic component of the polymer is converted by heat into high-value refinery products such as naphtha, crude oil or syngas. The main forms of feedstock recycling by thermolysis are pyrolysis (process carried out in a reducing atmosphere, i.e. in the absence of air), hydrogenation (process carried out in a hydrogen atmosphere) and gasification (process carried out with a controlled addition of oxygen).
The mechanical and chemical recycling require rather ambitious sorting while the thermolytic processes can more easily be fed with mixed polymers, even shredder residues can be used to these processes. The polymeric fractions sent to the recyclers for mechanical or chemical recycling most often need some further sorting and washing as a start of the process to turn the material into defined usable material specifications. Several books and reports about polymer recycling are available[8,9,10]. There is also a website for Plastics in End-of-Life Vehicles[11] where information about recycling and recovery of plastics from ELV's can be found.
Glass can also be recycled, see 3.3.2.5.

3.3 ELV treatment in Sweden

3.3.1 General

During the years 1997 to 2000, approx 150 000 ELV's were scrapped per year. 2001 and 2002, more than 250 000 ELV's were scrapped each year, due to a raise of the scrapping premium.

In the pre-treatment step in Sweden following items, according to the Swedish National Environmental Protection Agency's regulations and General advice on scrap vehicle operations, NFS 2002:2, are drained, dismantled or neutralized today:

- Oils (motor oil, transmission oil, gear box oil, hydraulic oils, brake fluid etc)
- Oil filters
- Fuel (petrol, diesel, gas)
- Other fluids (coolant/ glycol, washer fluid etc)
- Refrigerant from AC system

- Starter battery

- Components containing mercury
- Lead balance weights
- Pyrotechnical devices such as airbags and belt tensioners

Some fluids are most often reused, e.g. fuel and washer fluid, while others are sent to special companies for energy recovery. Lead batteries and balance weights are recycled (see Returbatt AB in 3.3.2.5). The mercury is disposed of in a controlled manner.
Catalytic converters and tyres are dismantled for re-use, recycling or recovery (see 3.3.2.5 Svensk Däcksåtervinning AB about tyres). From 2002, also the glass is dismantled (see 3.3.2.5 Miljöteknologi Midt-Norge AS) to reach the recovery quota set up by the Swedish Ordinance on Producer responsibility for vehicles. Other parts are dismantled to be re-used.
The metals are recycled after shredding and the shredder residue has up to now been put on landfill. Today, the shredders are investigating the possibilities to treat and recycle or recover the shredder residue as there are regulations that imply that current situation is not accepted.

3.3.2 Market actors

3.3.2.1 Dismantlers

About 600 dismantlers, in very much various sizes, exist in Sweden. Approx 80 of them are members of the dismantler network established by Bil Producentansvar Sverige AB (BPS), the automotive industry's common organisation for producer responsibility in Sweden.

3.3.2.2 Shredders

There are six shredder plants in Sweden at the moment[3]. Four of them are owned by the Stena Group and they treat approximately 650 000 tons of scrap each year (Halmstad, Hallstahammar, Huddinge and Malmoe). Other shredding companies are Skrotfrag AB (Gothenburg) and Arvamet AB (Skellefteå).

3.3.2.3 Metal recyclers

Recycling of metals has been performed in Sweden since the 17th century and there is a well-developed infrastructure for doing this. As much as 40% of the produced ironware are from recycled metal and as much as 60% of the stainless steel. When recycling metals from ELVs several actors are involved, first dismantlers and shredders as mentioned above. The metals processed at shredders are sorted and can be shipped directly to steelworks and foundries. There are also other actors on the recycling market who collects and sorts scrap which they sell on to steelworks and foundries. In order to simplify the buying of scrap metal for the steelworks and foundries a joint venture has been founded called Aktiebolaget Järnbruksförnödenheter. Aktiebolaget Järnbruksförnödenheter has published a scrap book which includes 24 classes of different scrap (iron and stainless). About one million metric tons are recycled every year (note: this figure includes not only metals from ELVs).

Some of the major metal recyclers

Collectors and Sorters	Steel mills and Foundries
Stena Gotthard AB	Outokumpu Stainless AB
M.V. Metallvärden AB	Fundia AB
Kuusakoski Sverige AB	AB Sandvik Steel
Lindberg & Son AB	SSAB Svenskt Stål AB
Förenade Järnskrotgrossister AB o CO KB	Ovako Steel AB
	Uddeholm Tooling AB
	Erasteel Kloster AB

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3.3.2.4 Plastic recyclers

There is no commercial recycling of plastic materials from the ELV's today.
Following selection of plastic recycling industries in Sweden is found in an IFP report[9] from 2002. Initially it comes from the source "AMI's guide to the plastics recycling industry in Western Europe", Bristol (1999).

Plastic recycling industry in Sweden[9]

	Polymers recycled									Products offered					Form of materials accepted			Recycling Technologies used							
	PE	PP	PS	PVC	PET	PA	PC	ABS	Others	Agglomeration	Regrind	Regranulate	Reprocessed	Finished products	Pre-sorted	Mixed bales	Contaminated	Separation	Size red./Regrinding	Sorting	Cleaning/Washing	Drying	Regranulating	Compounding	Agglomeration
AB Anders Hillertz	●	●	●	●	●	●	●	●	●		●	●							●	●	●		●	●	
AB Gotthard Nilsson	●	●	●					●	●					●		●	●			●	●				
Atervinning/ Recycling Husgärdet AB	●	●	●	●		●	●	●	●		●	●				●	●		●	●			●		
ERKA									●		●	●			●			●					●		
Forum International AB	●	●	●	●	●	●	●	●	●			●	●		●								●	●	
Gotthard Ragn-sells			●					●			●							●		●					
HA Industri AB	●	●	●					●			●	●		●					●	●			●	●	
IL Recycling Service AB	●										●					●			●	●					
LF Form AB	●											●			●								●		
Meltic AB	●	●		●	●							●							●		●		●		
Miljösack i Norrköping AB	●										●	●		●	●				●	●	●		●		
Nordkab AB	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	●	●	
Nya returab	●	●	●					●	●			●			●				●		●		●	●	
Plaståtervinning i Arvika AB	●	●	●			●	●	●			●	●		●		●	●		●	●	●		●		

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	Polymers recycled									Products offered					Form of materials accepted			Recycling Technologies used							
	PE	PP	PS	PVC	PET	PA	PC	ABS	Others	Agglomeration	Regrind	Regranulate	Reprocessed	Finished products	Pre-sorted	Mixed bales	Contaminated	Separation	Size red./Regrinding	Sorting	Cleaning/Washing	Drying	Regranulating	Compounding	Agglomeration
Plastic form AB	●	●	●		●							●			●						●		●	●	
Plastic recycling AB	●	●										●				●			●		●	●	●		
Plastretur AB	●	●	●		●	●	●	●	●		●	●			●				●					●	
Rondoplast AB	●	●	●			●	●	●	●		●	●	●		●			●	●				●	●	
Stema Plast	●		●				●	●	●		●	●		●	●				●				●		
Strandplast Perstorp AB	●	●	●								●				●				●		●	●		●	
Tarkett AB				●										●					●	●			●	●	
Trioplast AB	●													●	●				●				●	●	

3.3.2.5 Other recyclers

Svensk Däckåtervinning AB
www.svdab.se
There is a producer responsibility for tyres in Sweden and the tyres are recovered by Svensk Däckåtervinning AB. The tyres are treated in different ways e.g. retreading, recycling, reuse in other applications or for energy recovery.

Returbatt AB
www.returbatt.se
There is a voluntary agreement for recycling of batteries in Sweden. Returbatt AB coordinates the collection and recovery of batteries. Lead batteries, e.g. the starter batteries from vehicles, are recycled by Boliden Bergsöe (www.bolidenbergsoe.se). The lead content is recycled, the acid is neutralized and the plastic cover is used for energy recovery.
Lead balance weights from vehicles are also recycled by Boliden Bergsöe.

Miljöteknologi Midt-Norge AS, Norway
From 2002, the glass is dismantled and sent to the company Miljöteknologi Midt-Norge AS in Meråker, Norway. They produce foamed glass which is used as a road base[13].

3.4 ELV treatment in the European Union

3.4.1 General

In the European Union, approximately 7,5 millions of ELV's are treated per year[14].

The pre-treatment items are basically the same as in Sweden but some marginal variations can occur due to national or local regulations. Some countries, such as Greece, Spain, Ireland and UK, have introduced the obligation to pre-treat the ELV's very recently or are in the phase of introducing this obligation.
Parts are dismantled to be re-used. Tyres and catalytic converters might also be recycled or recovered. The metals are recycled after shredding. The shredder companies have the same situation as in Sweden; the shredder residues have up to now been put on landfill but now other possibilities to treat and recycle or recover the residues are under investigation as the current situation is not accepted.

3.4.2 Market actors

3.4.2.1 Dismantlers

The number of dismantlers (licensed enterprises) are[14]:

Country	No of dismantlers/ licensed enterprises
Austria	200
Belgium	18
Denmark	190
Finland	
France	1000
Germany	1178
Greece	0
Ireland	35
Italy	1800 (3000)
Luxembourg	1
Netherlands	700
Norway	144
Portugal	3
Spain	+/- 125
Sweden	600
UK	3600

Dismantlers infrastructure and activity are also described in the report "Dismantling" [5] from 2000.

3.4.2.2 Shredders

The total number of shredder locations are[14]:

Country	No of shredder locations
Austria	6
Belgium	12
Denmark	13
Finland	
France	42
Germany	
Greece	2-3
Ireland	2
Italy	18
Luxembourg	0
Netherlands	11
Norway	4

Country	No of shredder locations
Portugal	2
Spain	21
Sweden	6
UK	37

The report "Shredder Residue treatment and use" [2] from 1999 also describe the number, the size and the capacities of the ELV shredder facilities.

3.4.2.3 Metal recyclers

The recycling infrastructure for metals is established and economically feasible since years. No effort is spent to cover that topic in this report.

3.4.2.4 Plastic recyclers

Below follows a number of actors in the polymer recycling field. None of them can handle untreatad SR, the material input in their processes has to be sorted at least to some extent. The more careful the sorting is executed, the more cost-effective the following recycling process will be.
Some of the companies are already involved in automotive business, either by recycling scrap from production of automotive parts or by offering recycled materials for automotive use, and others are possible actors for the future. Some of the technologies are available on industrial base, others are under development.

Wipag
www.wipag.de
Wipag has a process that can separate multi-material automotive concepts such as carrier, foam and textile (e.g. the combination ABS, PUR and TPO). Shreddered material (very defined material combination consisting of a few different materials) are fed into a mechanical separation process where the material is ground in a special way so the different types of material are physically separated. Then the material mix enters a sorting step. First, the foam is sorted out due to its low weight. Secondly, the soft textile is sorted from the hard carrier. Today, Wipag is processing production scrap, mainly from the automotive industry or from suppliers to it, and return the carrier material back to the production of the original product.
To be able to sort a few number of different "hard" plastics, Wipag are investigating to add a supplementary sorting, probably some kind of density separation.
Wipag has two plants in Germany and also some joint ventures abroad.

Polymer-Chemie
www.polymer-chemie.de
Polymer-chemie separates shredded materials using hydrocyclones, which separate materials by density. Densities must differ more than 0,1 g/cm^3. They are e.g separating and recycling used automotive bumpers (PP based) collected from repair shops and also scrap materials from production of instrument panels (SMA, PUR and PVC).

Result
www.result-technology.com
Result has developed a delamination technology to separate multi-layer structures such as automotive instrument panels, multi-layer bottles or electronics. The different materials are separated layer by layer by a force generated in an accelerator between a moving rotor and a fixed stator. The process take advantage of different physical properties and reactions of materials, such as specific weight and density, ballistic characteristics, elasticity and malleability. The metals deform into globular shape while plastics more or less maintain their shape.
The Result process is not used for separation of automotive plastics today, it is mainly used for electronic scrap.

Grannex
www.grannex.de
Grannex recycle automotive parts e.g. bumpers (PP/EPDM or PC/PBT), radiator-bars (ABS) and hub caps (PA). These parts are collected from repair shops. Hydrocyclones (density sorting) are used to separate different materials. Grannex offers different recycled PP specifications.

WOMA
www.woma.de
WOMA's process can separate fibrous coatings/textile (e.g. PA) and backing materials (e.g. EPDM or PP/EPDM) in carpets[4]. They use high-speed waterjets to mill the backing materials from the textile card web without fibre damage. The fibres are separated for recycling. This technology is installed at a manufacturer of, among other parts, automotive carpets.

Delphi
www.delphiauto.com
Delphi has shown a melt centrifuge which separates materials having different melt temperatures. The materials to be separated are placed within a centrifuge which is heated to a temperature high enough to melt one of the materials. As the centrifuge rotate, the melted material is pressed, by the centrifugal force, through a grid towards the inside of the centrifuge shell where it is collected.
The technology is on an experimental level.

Vinyloop
www.vinyloop.com
Vinyloop is a selective dissolution process for PVC. The PVC rich material is ground and fed into a container with a mixture of solvents which dissolve the PVC. The insoluble residues are separated and the PVC is precipitated, dried and conditioned. The solvents are regenerated and reused.
Since 2002, Vinyloop has one industrial facility in Ferrara, Italy.

Wietek
Ulrich Schurr, teleno: +49 (0)6852/92100
Wietek is working with selective dissolution processes (see Vinyloop above for a brief description of such a process). They have one process for recycling PVC and another one for recycling ABS or ABS and PMMA. They have been contracted by the Dutch foundation Auto Recycling Nederland BV (ARN) to treat dismantled rear lamps (ABS and PMMA) from ELV's.

Getzner
www.getzner.at
Getzner produce PUR products used as e.g. vibration dampeners for railway or other construction applications. They use a chemical recycling process, glycolysis, to recycle the PUR scrap from their manufacturing. Getzner has more recycling capacity than internally needed and recycle externally produced PUR also.

3.5 ELV treatment in North America

ELV treatment in the US is quite similar to the one in Europe. Vehicles are to some extent dismantled and parts for reuse and remanufacture is obtained. Up to 10 to 12 million ELVs[15] are estimated to be retired every year. It is estimated that 95% of the retired vehicles are collected and that the recycling rate of ELVs is about 75% by weight - that is mainly metals and reused parts.

There are approximately 6000-7000 dismantlers in the US[16] () of which nearly 2000 are represented by the American Recyclers Association (ARA). ARA offers a certification program existing of two steps:

- *Certified Automotive Recyclers (CAR) Program*: Certification based on general business standards, as well as fulfilment of environmental and safety requirements.
- *CAR Gold Seal Program:* Advanced certification focused on customer service/ satisfaction and product warranties.

In the US the dismantlers can be divided into two categories:

- *High-value parts dismantlers*: Businesses that remove and inventory useful, high-value parts (e.g., starters and alternators) for resale. These operations target late-model ELVs and operate on a relatively high volume, – processing up to 400-500 cars per day. They serve repair shops located across the country. High-value parts dismantlers represent 20% of the dismantlers in the US.
- *Salvage/scrap yards:* Typified by traditional "U-Pull-It"- businesses, these are low-tech operations that essentially store ELVs while parts are gradually removed and sold. These companies serve mainly local repair shops and "do-it-yourselfers" and are often small family owned business.

Some pre-treatment are performed at the dismantlers. In North America ELV legislation such in the EU does not exist but there are regulations addressing solid and hazardous waste. In order to comply with these regulations fluids and batteries have to be removed before sending the ELV to the shredder.

After the useful / valuable parts have been removed from the ELV the hulk is sent to a shredder facility, and the metals are recovered. Metal recycling has been a profitable business for a long time and a well-developed infrastructure is available. In USA there are approximately 200 shredders operating which in 2001 recycled 15 million tons of steel and iron from automobiles.

The ASR is today sent to landfills, but some research is in progress how to decrease the volumes. As mentioned above there is no national legislation in the US regarding ASR, however there are some states that got restrictions of what can be landfilled and under which conditions. As for energy recovery it is uncommon in the US to recover energy from automotive materials with the exception of tires which are being recovered to 30%.

3.6 ELV treatment in Japan

In Japan the present situation is not that different from that in EU or the US, the ELV is treated at dismantlers and shredders ending up with a recycling rate of 75% by weight (reuse parts and metals). 5 millions vehicles are retired every year in Japan. Quite a large amount of ELVs and reused spare parts are exported - 1 million of retired ELVs are exported and 20% of reuse parts. The ELVs that are treated in Japan produces 500 000 - 800 000 tons of ASR / year which is sent to landfills. The shortage of landfill sites (among other things) has driven through the Automobile Recycling Law, which was enacted in July 2002 and will take effect in January 2005[17].

The law will force the OEMs and importer to:

- Recover three goods and recycle them properly
  1. CFC/HFC (recovery and destruction)
  2. Pyrotechnical devices (recovery and recycle)
  3. ASR (recovery and recycle, thermal or material use)
- Administrate recycling fees to be collected from each vehicle user, and fees to be paid to recycling businesses
- Make up for any shortfall of fees collected from users (in case of surplus, it will be added to benefit)
- Calculate and publicize the recyclability of three goods recovered (target for each item of the three goods is to be defined in the ordinances)
- Provide dismantling manual to dismantlers
- Reach overall recycling ratio of 95% (2015)

There are today approximately 5000 dismantler / shredders operating.

4. Conclusions

The EU Directive 2000/53/EC implies that the recycling and recovery from ELV’s shall increase. There are two ways to achieve this, either to extend the dismantling of parts prior to shredding or to introduce some kind of post shredder technology to recycle and recover the shredder residues which up to now most often have been put on landfill.

The metals, constituting 70-80 % of the weight of an ELV, are separated and recycled after shredding since years. Next big material group is the polymers, 10-20% of an ELV. The companies working in the polymeric recycling field today and mentioned in the report above, do process material inputs that are rather well sorted. They can not handle untreated SR. Technologies for treating SR, to sort out different recyclable and/or recoverable fractions, do exist and are very much under investigation/development today as the manual dismantling of ELV’s is costly. Recycling technologies for glass, < 5% of an ELV, do also exist.

There are a number of technologies available and there are many ongoing activities for finding out how to fulfil the recycling and recovery quotas to a minimal cost. Most probably, the shredding process will remain as the base in the total recovery chain.
The prerequisites, such as the amount of ELV’s to be treated and the market for the fractions/materials that are sorted out for recovery or recycling as well as national/regional regulations on waste handling, differ largely from one country to another, sometimes even within the same country. Probably, there will be national, or sometimes even regional, solutions to what to do to fulfil the recovery and recycling quotas.

5. References

1. U. Liljenroth "Shredder technology development and trends in Europe" December 2003
2. European Information Network for the development of Eco-effcient Treatment of End of Life Vehicles with the emphasis on Plastics Preliminary report – draft /working document "Shredder Residue treatment and use" March 1999
3. Volvo TC report 6700-03-04, C. Sjöberg, "Post-Shredder Treatment Technologies" 2003-01-08
4. ACEA Report "Recycling Infrastructure & Post Shredder Technologies" June 2002
5. European Information Network for the development of Eco-effcient Treatment of End of Life Vehicles with the emphasis on Plastics Preliminary report/working document "Dismantling" March 2000
6. Report 98.17. "ECRIS – ett forskningsprojekt för miljöanpassad bilåtervinning 1994-1998"
7. Spicer, M. Wang, P. Zamudio-Ramirez, L. Daniels "Disassembly modelling used to assess automotive recycling opportunities" SAE 970416
8. European Information Network for the development of Eco-effcient Treatment of End of Life Vehicles with the emphasis on Plastics Preliminary report/working document "Plastic materials recycling" May 2000
9. IFP Report Nr 02-009, Å. Svensson, "Polymer recycling for the automotive industry", 2002-05-16
10. J. Scheirs "Polymer recycling" 1998 (ISBN 0-471-97054 9)
11. Plastics in End-of-Life Vehicles www.plastics-in-elv.org
12. M. Weiss, A.W. Momber "Hydro-separation for textile automotive components recycling" included in the IFP report Nr. 02-030 "R´02 – The 6th World Congress on Integrated Resources Management at Palexpo, Switzerland February 12th – 15th 2002"
13. Bombardier Transportation report 3EST 7-3016 "Experiences of End of Life Treatment of Rail Vehicles" 2003-03-07
14. ACEA (European Automobile Manufacturer's Association) www.acea.be / Publications/ ELV Country Reporting Charts (28/05/2003)
15. SAE 2001-01-3744, SAE 2004-01-0246, Technical Approaches to Characterizing and Cleanup of Automotive Recycling Brownfields, EPA/625/R-02/001
16. Management of End-of Life Vehicles (ELVs) in the US, Jeff Staudinger and Gregory A. Keoleian, University of Michigan,Report No. CSS01-01
17. pers com., Masako Hamada, GM Asia Pacific

Websites

- BIL Producentansvar Sverige AB www.bilbranschen.com
- Svensk Däckåtervinning AB www.svdab.se
- Returbatt AB www.returbatt,se
- Boliden Bergsöe www.bolidenbergsoe.se
- Wipag www.wipag.de
- Result www.result-technology.com
- Vinyloop www.vinyloop.com
- Delphi www.delphiauto.com
- Polymer-chemie www.polymer-chemie.de
- Grannex www.grannex.de
- Getzner www.getzner.at
- WOMA www.woma.de
- ACEA (European Automobile Manufacturer's Association) www.acea.be
- Plastics in End-of-Life Vehicles www.plastics-in-elv.org

Appendix D

REPORT:

SHREDDER TECHNOLOGY

DEVELOPMENT AND TRENDS IN EUROPE

Ulf Liljenroth

Summary

This report is a part of a Design for Recycling project initiated by CPM, Competence Centre for Environmental Assessment of Product and Material Systems at Chalmers University of Technology in Gothenburg. It gives a state of the art report about shredder technology with particular focus on the situation in Europe. The report covers the situation today and also describes development trends for the future. Both technical and economical aspects are covered.

Every year up to 14 million motor vehicles cease to be roadworthy in the member states of the European Union (according to ACEA, European Automobile Manufacturers Association, approx. 7, 5 million of these are treated in Europe and the rest are exported outside the EU). To treat these vehicles there are over 220 automated vehicle recycling plants in the EU employing well over 6000 people, each functioning as an integrated factory, consuming worn-out vehicles at a rapid rate of up to 200 an hour.

Shredders originated in the late 1950s to deal with the increasing number of ELVs arising, as the old practice of hand dismantling could not keep up with even the relatively low volumes of ELVs in those days. Shredders have been steadily developed to increase efficiency, enhance the purity of the product, and especially to achieve optimum separation of the metals contained in a vehicle.

Not all separated materials are of direct use some residues are left over. There are two main types of residue: the airborne dust ('fluff') caught by the shredder dust collection system (consisting of upholstery fibres, dirt, rust, paint etc.); and the non-metallic residues separated from the recovered material streams by the media separation plant (consisting of unusable rubbers, plastics, stones, sand, glass etc.). These two residues are normally referred to as shredder residues (light and heavy fraction).

The shredder is and will remain a major process step in the recovery route of ELVs. At first shredders were developed to recover ferrous and non-ferrous metal from scrap cars and other goods. The purity and quality of these respective fractions are still subject to research.

Increasing efforts is also put into research how to further sort and prepare shredder residues. This is particularly important since the content of plastic and rubber material continues to increase in cars.

These efforts have several goals. The main reason is to increase the metal recycling level of the shredder operation and following steps. Still today the SR fraction contains metals, which can be sorted out by various methods.

In addition, sorting of the SR fraction will facilitate plastic recycling and recycling of other fractions like minerals and rubber. Last but not least, fractions can be tailored for use as fuel in combustion processes. As a consequence the amount of residues going to landfill will also decrease. Good examples of processes to sort the SR fraction can be found in Section 5 of this report.

Content

1. Introduction

The main driving force for improving the shredder operation is to increase the recycling level of metals. A second effect is that recycling of other materials and use of residues as fuel will divert material from landfill and therefore reduce future landfill costs. The European End-of-Life-Vehicle Directive 2000/53/EC is also a reason for further development of the shredder process and following recovery operations.

The report gives a state of the art report about shredder technology with particular focus on the situation in Europe. The report covers the situation today and also describes development trends for the future. Both technical and economical aspects are covered. Particular focus is devoted to description of the various output fractions of the shredder operation and following recovery/recycling operations.

The report is a part of a Design for Recycling project initiated by CPM, Competence Centre for Environmental Assessment of Product and Material Systems, at Chalmers University of Technology in Gothenburg.

Purpose

The purpose of this report is to describe the shredder process and following processes to recover and/or recycle materials from ELVs and other industry goods.

Objectives

The objective is to give brief descriptions of the shredder business in Europe today and also to indicate interesting development trends.

Scope

This report covers technologies used today and development trends. The report focuses on the situation in Europe. However some information about the international situation is also mentioned.

Methodology

The base for this report is information gathered from shredder actors and actors connected to the shredder business in Europe as well as reports and articles published on the matter.

2. General aspects of shredder technology with particular focus on Europe

Picture 2.1. Material inlet of a shredder.

Every year up to 14 million motor vehicles cease to be roadworthy in the member states of the European Union (according to ACEA, European Automobile Manufacturers Association, approx. 7, 5 million of these are treated in Europe and the rest are exported outside the EU). To treat these vehicles there are over 220 automated vehicle recycling plants in the EU (and over 700 world-wide) employing well over 6000 people, each functioning as an integrated factory, consuming worn-out vehicles at a rapid rate of up to 200 an hour. By a powerful shredding action, vehicles are processed into high-density fist-size pieces. The separated shredded ferrous scrap obtained is well suited to direct feeding into a steel-making furnace. This material has a ferrous content of 98%. In the EU alone, shredders produce over 8 million tonnes of this furnace feed material annually - around a third of total world output.

Shredders originated in the late 1950s to deal with the increasing number of ELVs arising, as the old practice of hand dismantling could not keep up with even the relatively low volumes of ELVs in those days. Shredders have been steadily developed to increase efficiency, enhance the purity of the product, and especially to achieve optimum separation of the metals contained in a vehicle. Many vehicle components are made of non-ferrous metals such as copper, aluminium and zinc. In the shredding process, magnetic separation is used to remove the magnetic ferrous fraction from the other materials, leaving non-ferrous metals to pass to further stages for the segregation of one type from another. Eddy-current separators induce energy that will literally project one non-ferrous metal from another and any surrounding materials. Other high technology devices, like media separation, are also used for separating shredded materials.

There are over 40 media separation plants in the EU. The purpose of these units is recovery of non-ferrous metals. The separation takes place after the separation of ferrous metals at the shredder. The operation can be located at the shredder site or elsewhere. Media separation plants employ fluids or mineral suspensions of varying specific gravity that allow selected materials to float while the others sink. Thus a succession of different media separation stages within a single plant can effectively separate materials one from another. Media separation plants currently recover around 99.5% of the non-ferrous metals from shredded vehicles and progress is being made to capture the other half percent.

Not all separated materials are of direct use but some residues are left over. There are two main types of residue: the airborne dust ('fluff') caught by the shredder dust collection system (consisting of upholstery fibres, dirt, rust, paint etc.); and the non-metallic residues separated from the recovered material streams by the media separation plant (consisting of unusable rubbers, plastics, stones, sand, glass etc.). These two residues are normally referred to as shredder residues (light and heavy fraction).

The aspirated dust and the separated residues together represent about 17 to 25% of the average vehicle weight. These residues have been land filled, representing approximately 0.2% of total landfill waste in the EU (ref. 22). However, progress in media separation technology is continuing and now enables some further materials to be recovered, while the remaining combustible materials may have considerable potential as a fuel. Research and development continues in this area and is covered later in this report.

The EU's shredder and media separation infrastructure is economically self-supporting, furthermore being able to process millions of redundant cookers, washing machines and similar consumer durables which would otherwise pose a large disposal problem. These plants provide processed materials to consumers worldwide, generates revenue for exporting countries and (as secondary materials are normally less expensive than primary materials) offers a cost advantage to the industries that consume them.

The use of secondary raw materials is highly beneficial, providing appreciable energy savings and producing fewer emissions. Recycling iron and steel saves 74% of energy and 86% of emissions compared with primary production. For other materials, energy savings are: 95% for aluminium, 85% for copper, 65% for lead, 60% for zinc and over 80% for plastics (ref. 22).

2.1. Wet and dry shredder technology

A new trend in North America is that practically all new shredders employ wet, semi-wet or damp (spray injection) processes. The dry shredder technology is the most practiced system in Europe. This system will be explained in detail in Section 3. The fact that wet shredding has not caught on in Europe is due mainly to higher costs of residue dumping. Wet shredding makes the fluff (light fraction) heavier, so companies have to pay additional dumping costs for the water that has been absorbed in the residues.

Earlier around 250 litres of water per minute used to be sprayed into wet shredder processes. The amount of water has now been reduced to 40 or 50 litres per minute (ref. 23). A very recent development is the injection of a specially developed foam-extinguishing agent that is combined with the water.

The mixture of water and foam cools the rotor, reduces the risk of explosions and rinses the scrap. In addition, the need to extract dust from the shredder is reduced because less dust is released.

2.3. Number of ELV shredder facilities

BIR (Bureau of International Recycling) information gives the geographical distribution of shredder plants through out Europe. BIR is an international trade federation representing the world's recycling industry, covering in particular ferrous and non-ferrous metals, paper and textiles. Plastics, rubber and tyres are also treated and traded by some BIR members.

The southern European countries of Europe have fewer shredder sites, see Table 2.3.1. Northern Italy has a concentration of shredder sites. For France, the shredders are situated close to the largest urban centres.

EUROPE		World	
BENELUX	23	USA	187
DENMARK	5	JAPAN	185
FINLAND	3		
FRANCE	48		
GERMANY	56		
ITALY	18		
NORWAY	4		
PORTUGAL	2		
SPAIN	14		
SWEDEN	6		
SWITZERLAND	5		
UK	47	**Total globally**	806

Table 2.3.1. Number of shredders per some countries inside and outside of the EU (Ref. 21)

2.4. Size and capacity of a shredder

Shredders are characterized by their engine power. The largest units are in the 7000 hp (1 horse power is 745.70 Watt) range. The capacity of a large shredder is huge. 200 tonnes of scrap can be processed per hour in a 6-7000 hp shredder. In the US, the size averages around 4000 hp. The lowest are in the 1000 hp range. Japan average size seems below 1000 hp. Shredders in Europe range from 1250 to 2000 hp, with some exceptions.

2.5. Example of shredder manufacturers

NEWELL and LINDEMANN are two examples of shredder manufacturers. Most of Europe is equipped with medium size machines, such as LINDEMANN shredders, see Figure 2.5.1.

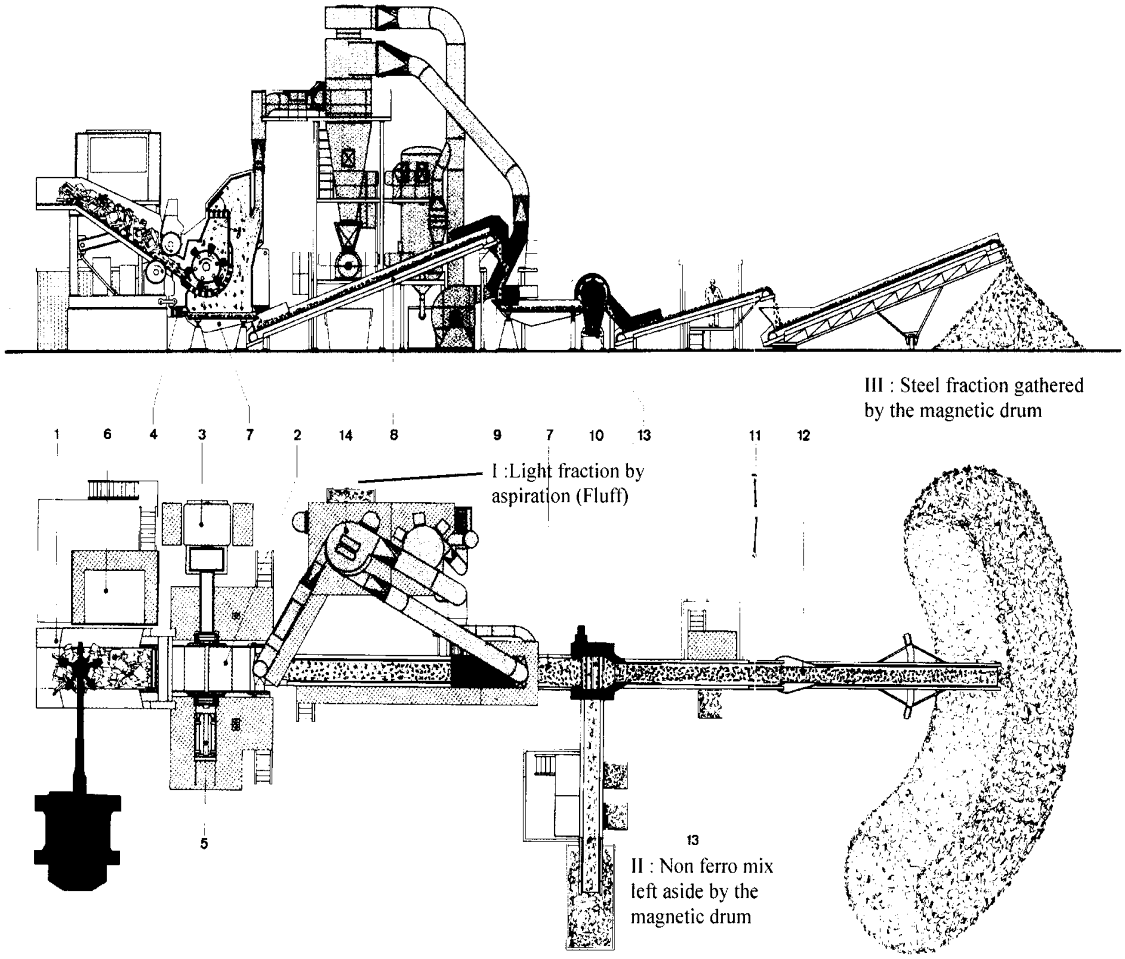
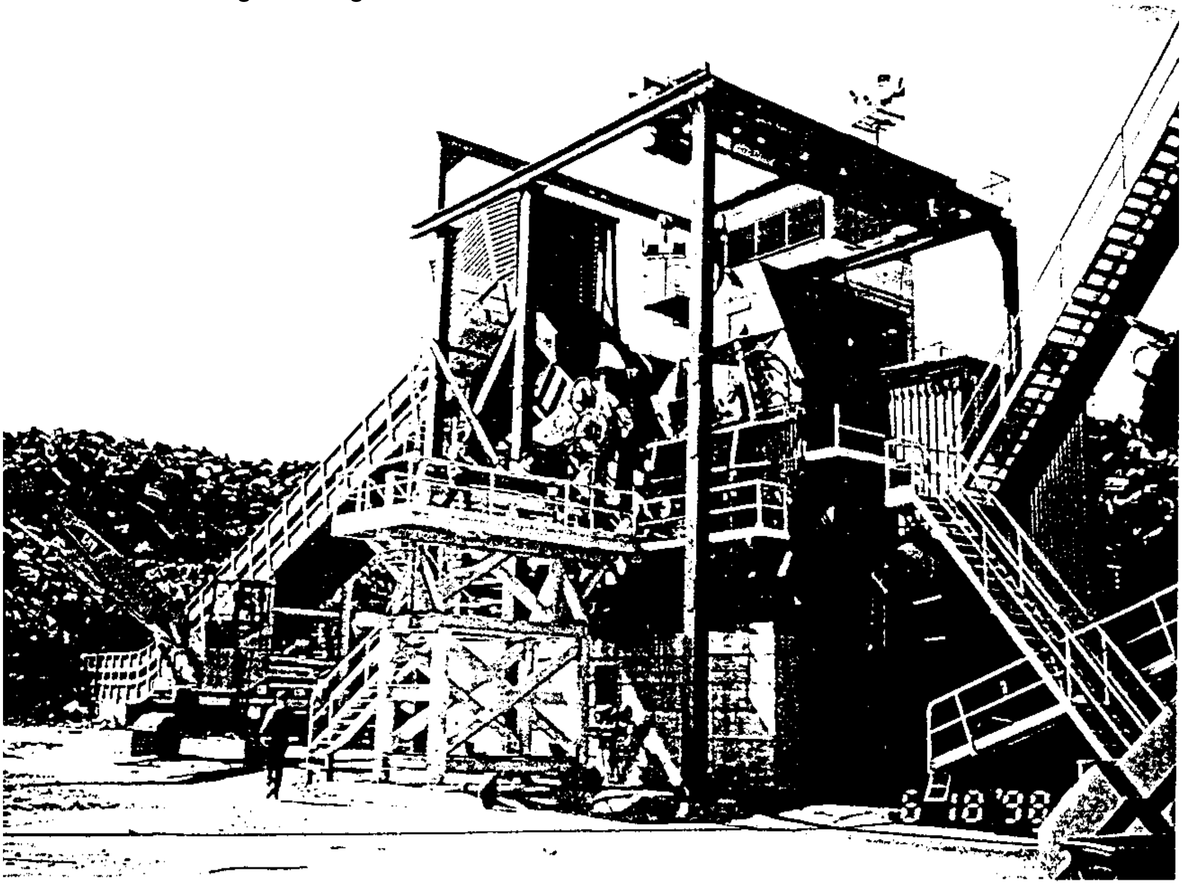


Figure 2.5.1. LINDEMANN shredder layout and technology

1 Feeding chute with tilting table
2 Zerdirator with upper and lower grid
3 Main drive motor
4 Vibration absorber
5 Hammer dismantling device
6 Control cabin
7 Vibrating conveyor
8 Belt conveyor
9 Air sifter
10 Magnetic drum
11 Steel sorting belt
12 Steel discharge belt
13 Non-ferrous metal sorting belt
14 Dust extraction equipment

NEWELL has produced more than 100 heavy duty and super heavy-duty units since 1980. There are 70 NEWELL machines in the U.S., and exports include 12 machines to Italy and 30 to other parts of the world. The NEWELL 6 000 hp mega shredder at Transider, Naples, Italy, is shown in Picture 2.5.1. The machine has a rotor diameter of around 245 cm and a width of around 212 cm. The hammers weigh 450 kg each.



Picture 2.5.2. NEWELL shredder at Transider, Naples, Italy

2.6. Specific European countries and their shredder industry

A general trend is that shredders, especially the larger ones, were taken over by steel manufacturers; this is the case in Germany, the Netherlands, Belgium, the UK and Italy. The advantage for steel manufacturers is that they can control the re-use of their own production scrap.

Benelux (i.e. Belgium, Luxembourg and the Netherlands)

Galloo owns four plants, one shredder plant (Menen: 70 000 tonnes/year), one heavy medium plant (Menen: 70 000 tonnes/year) and two shredder residue treatment plants (Menen: 50 000 tonnes/year, and Châtelet: 100 000 tonnes/year) owned by Galloo and Cometsambre.

Galloo has been quite innovative in recycling and recovering of the non-ferrous metals and the shredder residues via different technologies. The possibilities and technologies used by Galloo in their shredder residues treatment line (SRTL) are further explained in Section 4.2.

France

In France, shredder companies are privately owned. There are about 40 shredder plants: CFF (Compagnie Française des Ferrailles) is the largest company, with shredder plants in France (22), in the rest of Europe (3) and outside Europe (5). They treat 3.8 million tonnes of scrap ferrous metal and 269 000 tonnes of non-ferrous metals per year. They generate 400 000 tonnes/year of shredder residues.

CFF has co-operated with PSA (Peugeot-Citroen) in a vehicle disassembly project. CFF has also cooperated with PSA and VICAT (cement plant company) in a pilot project on scrap car treatment (VALERCO project). This project investigated ways to recycle and recover different materials in order to leave minimum waste quantities for final disposal in landfill.

GALLOO is another operator with three shredder plants, one plant in Halluin Northern France with a 150 000 tonnes/year capacity, Lille: 50 000 tonnes/year and Douai: 50 000 tonnes/year. Furthermore Galloo operates a shredder residue treatment plant (Halluin: 100 000 tonnes/year) and one plastic recycling plant (Halluin: 12 000 tonnes/year).

SOFIVAL is a group of recycling related companies. These companies have been actively involved in research on shredder residue energetic recycling for a number of years. In 1998, seven new shredding firms entered SOFIVAL shareholding structure and four shredding companies signed partnership agreements with SOFIVAL.

Germany

In Germany, there are 40 shredders in operation, almost all are members of the German shredder organisation. Most shredder companies cooperate since 2002 with ARGEcar-net (Arbeitsgemeinschaft Netzwerk Altfahrzeugrecycling). This network between shredders and dismantlers has been established to secure a proper pre treatment of cars (draining of oils, removal of battery etc.) before the car is processed in a shredder.

According to German law, shredders are obliged to reduce the final residues that goes to landfill. Until 2015 the amount of material going to landfill must not exceed 5% of the material input to the shredder. The reduction from today's landfill level (approximately 25% weight) must have started already 2002.

Italy

The Shredding Industry in Italy has been under development since the early sixties mainly as a necessary upstream support to the growing steel industry based on electric arc furnace. The electric arc furnace technology requires iron scraps instead of iron ore. The ELVs were seen as an excellent source of raw material, therefore the shredding activity was initiated by the steel industry. For this reason the number of shredders is relatively limited compared to other countries and steel producers own most of them. On the other hand the average size of the shredder plants in Italy is larger than in other European countries.

Sweden

Sweden's main shredding facilities are operated by Stena Gotthard Fragmentering and are located in Halmstad, Huddinge, Hallstahammar and Malmö. Skrotfrag is another company, which has operations in Göteborg and Jönköping. Together they are handling about 500 000 tonnes of scrap metal per year.

United Kingdom

Phillips Services Corporation has shredder operations in the UK, for example a 7000 hp shredder at Avonmouth.

The largest shredder company in the UK (on tonne/year basis) is Mayer-Parry-Robinson, which processes about 36% of the total scrap material in the UK. Mayer-Parry-Robinson has a 6000 hp unit at East Tilbury, a 5000 hp unit at Willesden and smaller units elsewhere.

The small size advantage is important because it enables flexibility of the operation, which also allows cost-effective separation of a wide range of materials with sophisticated technologies. Some of these companies actually buy in shredder residues from other operators in order to recycle the non-ferrous metals contained in the residues.

3. Dry shredder process – technical explanation

Scrap materials to be shredded are loaded into the feeding chute of the shredder. The scrap is fed into the shredder housing bi-directional input roller drums, where shredding takes place through the effect of the hammers on the scrap against the blades and the grids. The shredded scrap leaves the machine when the granulation is small enough to be pushed through the grates.

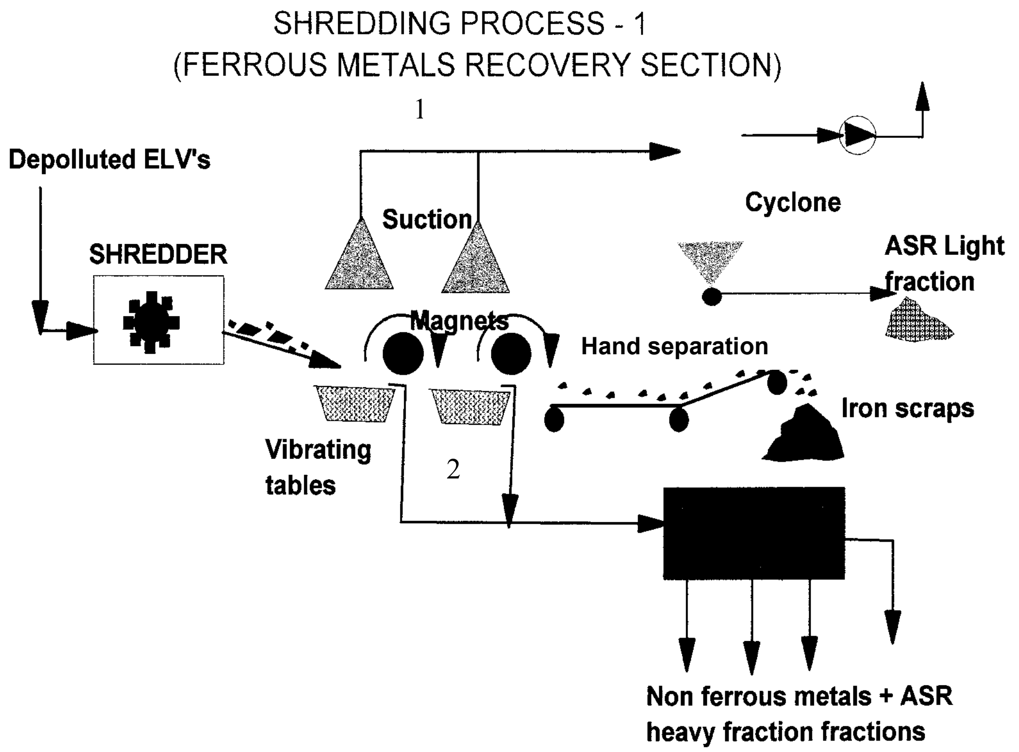


Figure 3.1. Layout of a shredder process, step 1 (Ref. 24)

The shredded materials are taken to an air separation unit by a conveyor belt. Here, a first separation through suction is made, see Figure 3.1 (1). By means of an air classification, the light fraction (fluff) is separated from the rest. This fluff is separated from the air current via a cyclone. Fluff consists mainly of: polyurethane foam, textiles, light plastics, small wood pieces wood and other light materials.

To clean the out coming air the air stream is forced, either through a sleeve filter, or through wet washing of the air. In the latter case, sludge is generated at the shredder site.

After air classification of the light fraction, a second separation, see Figure 3.1 (2) is made. The ferrous fraction is drawn onto a magnetic drum. In this way, the main fraction of a shredder installation is obtained. In order to meet the requirements of the steel industry, one or more hand-pickers watch over the quality of the ferrous scrap. Some unwanted materials are sorted out of the scrap by hand, i.e., mostly ferrous parts that are polluted with unwanted material, for example, starter rotor (i.e. Cu), electrical wires and tire pieces (i.e. rubber).

The third fraction, see Figure 3.2 (3), is the refuse of the magnetic drum. This is called the non-ferrous (NF) mix. The non-ferrous mix mainly consists of NF metals (Al, Mg, Cu, brass, Cu-Zn, Stainless steel, Pb etc) and the heavy residues (rubber, wood, plastics etc) and inorganic fractions (glass, stones, mud, sand etc).

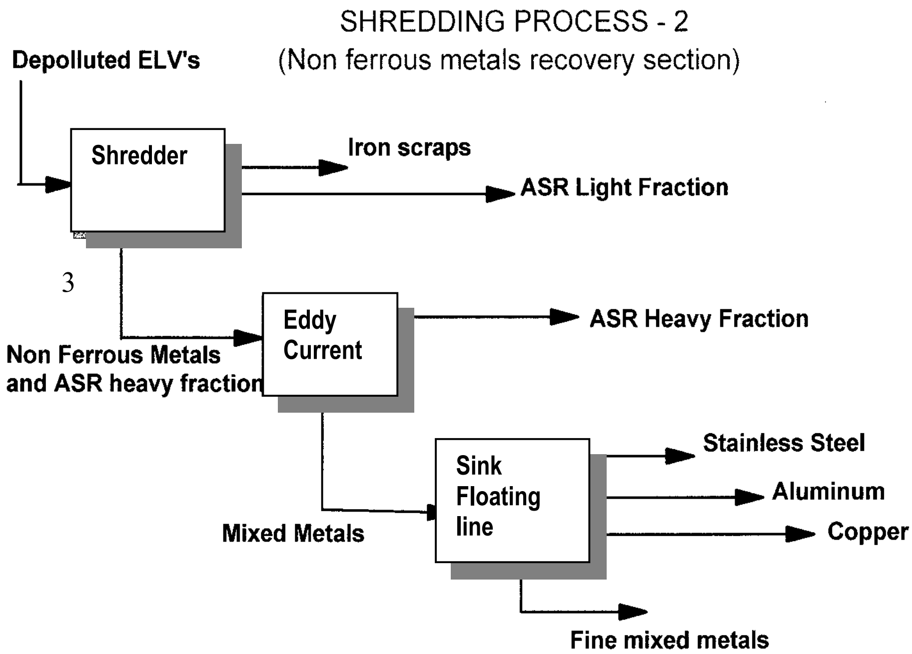


Figure 3.2. Layout of a shredder process, step 2 (Ref. 24)

At some shredder plants an Eddy Current unit is installed to separate NF-metals from heavy residues. Eddy Current separation is using the following principle. At the shredder a conveyor belt with a rotating magnet is installed in the head drum of the belt. This rotor is equipped with a number of zones of alternating north and south orientated permanent magnetic material. The rotor produces an alternating magnetic field. If conductive particles are exposed to this alternating magnetic field, within them eddy-currents are generated. On the other hand, these eddy-currents affect magnetic fields, which act against the inducing fields, whereby repulsive forces are generated and the non-ferrous metals are deflected from the main particle stream.

Last step is a heavy media separation for further treatment (e.g. further separation of the NF-metals from the residues and separation of the different metals) (sink floating line in Figure 3.2). Not all shredders are equipped with a heavy media separation unit. Altogether there are over 40 media separation plants in the EU located in connection to a shredder or separately. Media separation plants employ fluids or mineral suspensions of varying specific gravity that allow selected materials to float while the others sink (sink floating line). Thus a succession of different media separation stages within a single plant can effectively separate materials one from another. Media separation plants currently recover around 99.5% of the non-ferrous metals from shredded vehicles and progress is being made to capture the other half percent.

To conclude:

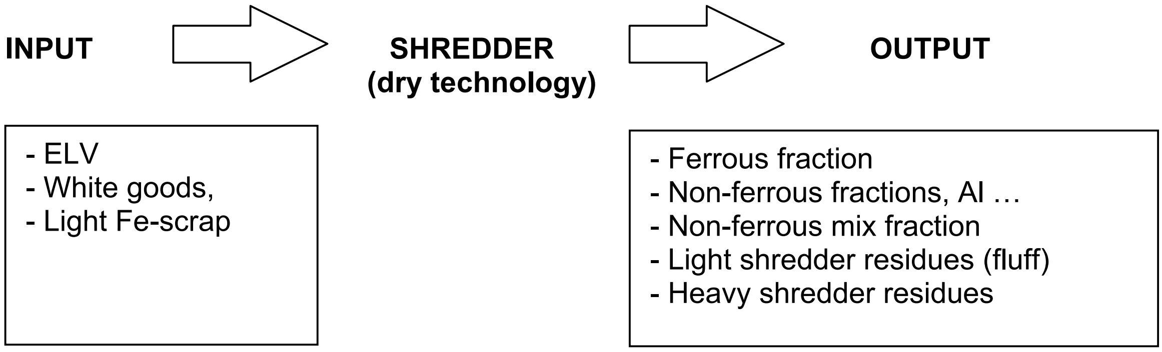


Figure 3.3. Input and output of a typical dry shredder operation

4. Material balance of the shredder operation

4.1. Metal fractions from shredder operations

The material content in metal fractions out from shredder operations is presented in Table 4.1.1. These figures are representative for a general shredder operation. This means that the shredder input is a mixture of ELVs, white goods (refrigerators and cookers etc.), brown goods (TV and other entertainment products) and municipal waste metallic scrap.

In order to evaluate how much of the original input of metals that end up in the recycled fractions the metal content in the ASR must be studied, section 4.3.

Fe, ferrous fraction	Fe 98% (range from 95-98%), Cu 0.20-0.25% (down to 0.01% feasible), rubber etc.
Stainless steel, alloys	Purification of 98-99%, the rest is other non ferrous metals
Aluminium, alloys	Purification of 98-99%, the rest is other non ferrous metals
Copper, alloys	Purification of 98-99%, the rest is other non ferrous metals
Fine mixed materials	Alloys: Cu-Zn,Cu-Sn Zn...

Table 4.1.1. Metal output from the shredder in average European figures (Ref. 22)

4.2. SR fraction from general shredder operations

The shredder residue production in tonnes in Europe is estimated in Table 4.2.1. These figures are representative for a general shredder operation (1998). The shredder input is a mixture of ELVs, white and brown goods and municipal waste metallic scrap.

An average ELV today weighs approx. 1000 kg, of which 75% is recovered as metal. Hence the remaining materials become SR (25%). If ELVs are not part of the shredder input the SR fraction usually increases.

Country	Production (1000 tonnes)
France	600
UK	502
Germany	500
Italy	456
The Netherlands Light fraction Heavy fraction	120 50
Belgium Light fraction Heavy fraction	90 30
Finland	76.5
Denmark	78
Sweden	100
Norway	64.5
Switzerland	40
Total Europe Light fraction **Heavy fraction**	**2000** **500**

Table 4.2.1. Shredder residue production in tonnes in Europe (Ref. 21).
Shredder residue consists of many types of plastics (thermoplastics and thermosets), foams, rubber, textiles, glasses and metals (such as iron, aluminium, copper, zinc, and lead). Shredder residue composition will vary depending upon type of shredding operation and country considered.

The variation of the material composition of general shredder residue in Europe is outlined in Table 4.2.2. The data have been reported by different publications or communications through Europe (1998).

		min	**EU, mean**	**max**
Lower heating value	GJ/t	13.5	14.65	17
Ash/inert	wt%	6.2	43.23	55
Ferrous metal	wt%	3	11.7	15
Aluminium	wt%		2.1	
Magnesium	wt%		0.78	
Copper	wt%		1.78	
Pb	wt%		1.2	
Zn	wt%		1.5	
Halogens	wt%	0.4	2	3.6
Heavy metals	wt%	0.2	1	2.2
Moisture (large variation depending on storage conditions, wet/dry, of products)	wt%	5	5.00	43
Chlorine	wt%	1.3	1.76	2.4
Sulphur	wt%	0.5	0.70	1
Rest, mainly organic material			27.25	

Table 4.2.2. Composition of the shredder residue in Europe (Ref. 21). These figures relate to a general shredder operation, i.e. the shredder input is a mixture of ELVs, white and brown goods and municipal waste metallic scrap.

4.2.1. Content of hazardous substances in shredder residues

The average content of hazardous substances in shredder residues is given in Table 4.2.1.1. These figures are based on measurements in various European countries inside the EU community and are representative for a general shredder operation. This means that the shredder input is a mixture of ELVs, white and brown goods and municipal waste metallic scrap.

Heavy Metals		EU mean
Cd	mg/kg	61.1
Tl	mg/kg	0.8
Hg	mg/kg	6.3
Sb	mg/kg	707.0
As	mg/kg	42.7
Pb	mg/kg	5928.3
Cr	mg/kg	781.0
Co	mg/kg	26.0
Cu	mg/kg	20640.0
Mn	mg/kg	787.5
Ni	mg/kg	612.3
V	mg/kg	31.0
Sn	mg/kg	398.5
Zn	mg/kg	8942.3

Table 4.2.1.1. Hazardous substances in general shredder residues (Ref. 21).

4.3. Material composition of ASR (light and heavy fraction)

Through analysis, the material content in ASR (automotive shredder residues) has been obtained (Ref. 6, 14). Generally speaking 25 wt% of the ELV input becomes ASR (light and heavy fraction in combination). The proportion between the light and the heavy fraction is approximately 1:3 by weight. Typical figures for the light fraction (ASR light) are presented in Table 4.3.1 and for the heavy fraction (ASR heavy) in Table 4.3.2. Metal content of the shredder residue from disposed automobiles is generally lower than one from disposed electric appliances.

Material	Composition and particle size	Content (wt%)
Polymers	2–10 cm	9
Foams PUR	10/10–20/20 in cm (size of PUR pieces in the residues)	8
Rubber	Long pieces (gaskets seals), no tires	3
Metals	Wires / Al plates	2.5
Cu wires	Length: 10–20 cm	1
Wood	Pieces 10–20 cm	1
Mixed PUR with textiles	Textiles, carpets, leather etc	32.5
Minerals	Stones, sand, glass, dust etc	43

Table 4.3.1 Content of ASR light fraction (Ref. 2).

Material	Composition and particle size	Content (wt%)
Polymers		19
Rubber	Tires (45%), seals and gaskets (55%)	55
Metals	Fragmentised Fe and non ferrous metals	5
Wood		7
Textiles	Small pieces	3
Cu wires	Cable (5–15 cm)	3
Minerals	Stones, up to 100–500 g/piece	8

Table 4.3.2. Content of ASR heavy fraction (Ref. 2).

Taking the individual content of the ASR light and heavy fraction as well as the approximation that the proportion between the light and the heavy fraction is 1:3 by weight it becomes possible to calculate the proportion of different materials in the total ASR fraction.

Material	Composition and particle size	Content (wt%)
Polymers		12
Foams PUR		6
Rubber	Tires, seals and gaskets	16
Metals, ferrous		2
Metals, non-ferrous		3
Wood		2
Mixed PUR with textiles	Textiles, carpets, leather etc	25
Minerals	Stones, sand, glass, dust etc	34
	Sum	100

Table 4.3.3. Proportion of different materials in the total ASR fraction.

5. Emerging technologies to further refine the output of the shredder operation

5.1. Removal of chlorine containing material

There are two main problems with chlorine content in shredder residues (SR). Firstly, chlorine contributes to formation of corrosive gases in the incineration system. Secondly, chlorine may, under certain incineration conditions, form dioxins.

In 1997 RENAULT started a state of the art study on existing processes and facilities to extract chlorinated materials from SR (Ref. 1). The objective was to find new techniques able to achieve the separation of these products to obtain substitute fuels from SR with lower chlorine content. An evaluation of existing techniques showed that it was not possible to use or optimise *density separation* in order to meet chlorine requirements for SR used in energy recovery. *Electrostatic sorting* was one potential way but the humidity level in the SR need to be controlled at a constant level. However identification of chlorine through *RXF (radioactive florescence)* was found as a feasible method.

Renault set up a consortium of partners that had interest in the development of an automatic separation process for chlorinated materials in SR. According to the results obtained during the first step of the project the Consortium felt confidence to be able to develop a pilot in France. The overall objective is to industrialize the process and sorting equipment for use at recycling and/or car shredder facilities.

Another development project is the extraction of a chlorine-containing fraction during the preparation of the shredder light fraction. This project is considered at the Belgian Scrap Terminal (Craenhals) at Willebroek.

An additional method of removing chlorine-containing material is mentioned in Section 5.2 (fraction E in the SRTL process).

5.2. Galloo integrated technology – metal and plastic recycling in combination

The Galloo Shredder Residue Treatment Line (SRTL) is a downstream operation complementing and upgrading the basic shredder treatment (Ref. 2, 20). The main driver for SRTL action is to divert products from landfill to energy and to increase material recycling. Galloo has developed a technical solution to extract valuable materials from shredder residues (SR) that can be considered economically as well as ecologically viable. The know-how covers mechanical separation of heterogeneous fractions. The two main functions of the SRTL are to increase the metals collection from the residues and to prepare new fractions of products for both material recycling, energy recovery and feedstock recovery processes.

The Galloo group operates three SRTL since 1995. Plants are located in Menen, Flanders, in Belgium (65 000 tonnes/year), in Charleroi, Wallonia, in Belgium (100 000 tonnes/year), and in Halluin, Nord Pas-de-Calais, in France

(100 000 tonnes/year). The Galloo Recycling group includes recycling companies for ferrous and non-ferrous metals in Western Europe.

The running cost for the SRTL as described above, including investment, is estimated at around 25 Euro/tonne (year 2000). The cost includes investment, labour, energy, material and maintenance. This cost does not include further treatment steps at Gallo-Metal, Galloo-Plastics etc.

The treatment line can subdivide the shredder residues into five main fractions (A to E plus additional iron collection, fraction F). The layout of the treatment line is explained in Figure 5.2.1.

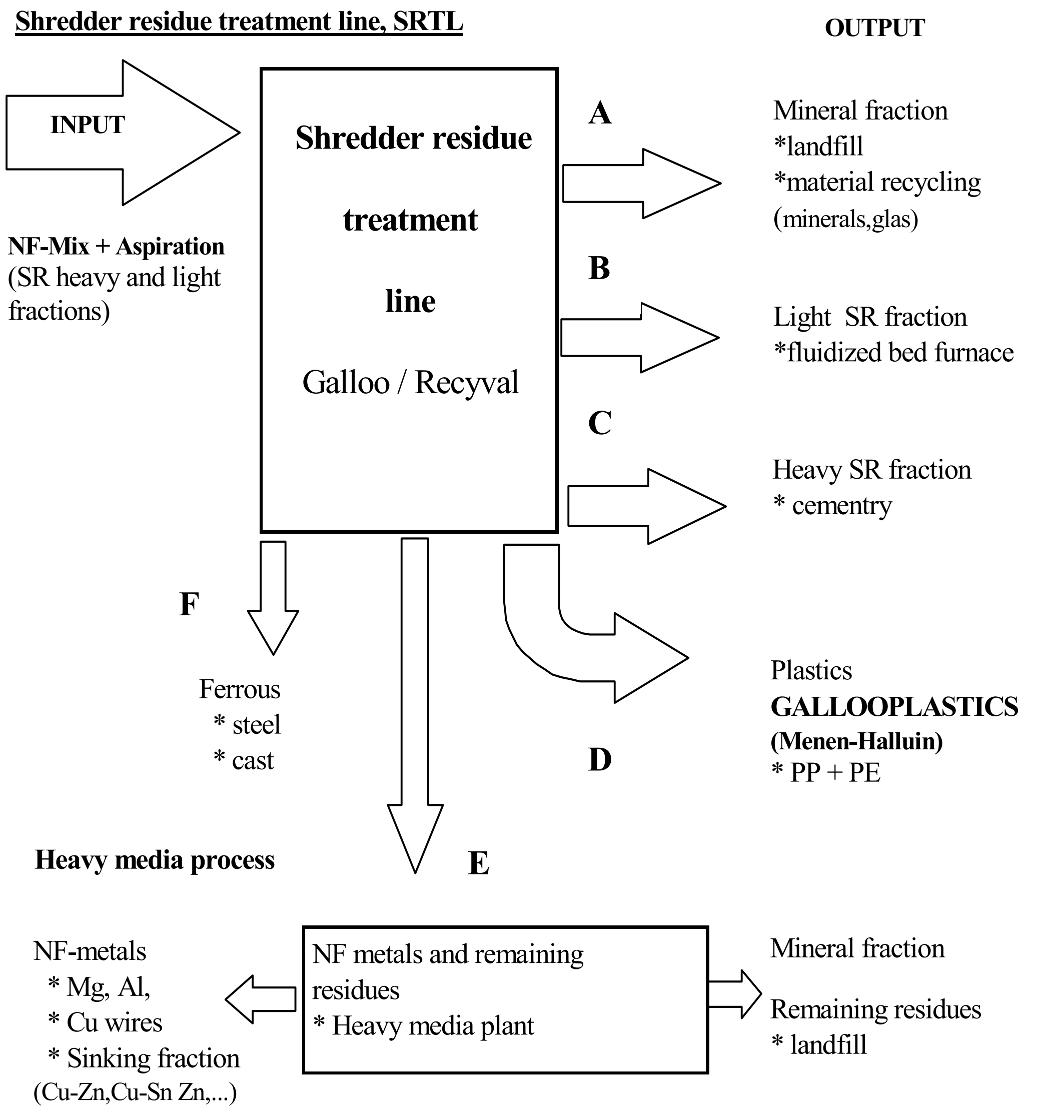


Figure 5.2.1. General layout of the Galloo shredder residue treatment line (Ref. 2, 20)

A) Mineral fraction (approximately 40% of the material output)
Currently, this fraction (glass, gravel and sand) seldom find any usage, normally it is land filled. Research is being carried out to investigate the upgrading of this fraction for the road construction industry. The recovery of this fraction is an important issue for the further improvements of the SRTL process.

B) Light fraction (30% of the material output)
This fraction consists mainly of foam and textiles. It comes mainly from the light shredder fluff. Currently Galloo is working with a supplier to car industry to prepare sound insulation materials for vehicles using foam extracted from this fraction. An alternative is to use this fraction for energy recovery.

C) Heavy combustible fraction (15% of the material output)
It contains mainly rubber, polymers and wood. The calorific value of the mixture is 26 MJ/kg. The cement industry in Belgium and Northern France was particularly interested in the 1990's in this fraction of reliable quality to be used as a solid fuel substitute. From 1995 to 2000, 15 000 tonnes/year have been recovered in the Belgian cement kiln of C.B.R. at Antoing as a Refused Derived Fuel (RDF) substituted to solid coal fuel. Today the volume is close to 4 000 tonnes/year, due to the competition of other RDF, including plastic waste from other sources.

D) Plastic fraction (10% of the material output)
Today polyolefin's (PP + PE) are recovered from this fraction by Galloo Plastics. They are transformed by extrusion into ready to use compounded granulates, which are sold to plastic moulding industry (production capacity of compounded granulates in 2002: 18 000 tonnes/year). In addition a continuous production of polystyrenes granulates started in 2002. Today the main reason for running the SRTL process is recycling of plastics. Further improvements are being made to recover all the thermoplastics such as ABS, PA, PC, etc.

E) Remaining residues (5% of the material output)
This fraction contains high chlorine containing plastics, stones and non-ferrous metals. This metal fraction is further separated by a heavy media step (e.g. at GALLOO METAL). The high chlorine containing plastic fraction is land filled today. Stones are recycled for use in the road construction industry.

5.2.1. Results from a trial where ELVs were shredded using the Galloo SRTL process

During 2001, PSA (Peugeot Citroën SA) and Renault conducted a full size experiment with Galloo in order to evaluate the actual ELV recovery rate of the overall shredding and post-shredding technologies and sorting engineering developed by the Galloo group and now available on an industrial scale (40 tonnes/hour). A trial was conducted on 201 ELVs (PSA and Renault vehicles) during the winter of 2002.

All ELVs shredded were "complete" (i.e. no components were removed for reuse) and depolluted (drained from fluids, removal of battery etc.) according to Belgium environmental requirements. The trial included the polyolefin sorting step (PP=polypropylene, and PE=polyethylene) as well a polyamide sorting step now available for production of compounded granulates.

PSA and Renault calculated the material composition of the 201 shredded vehicles, in order to set a mass balance of the trial (inlet versus outlet).

In order to compare differences and improvement in the Galloo post-shredding techniques, ELVs shredding results were compared from the following three periods.

1) Before 1995: complete shredding plant and flotation unit for ferrous and non-ferrous recycling, no plastic recycling, and no energy recovery. This situation is further defined as “standard” shredder operations. See black line in Figure 5.2.1.1.

2) From 1996: operation by Galloo of the SRTL (Shredder Residues Treatment Line). This includes additional metal recycling and energy recovery (RDF) in cement kiln.

3) From 2002: operation of the Galloo-Plastics plant and additional recovery gained by the Galloo official ELV depollution centres.

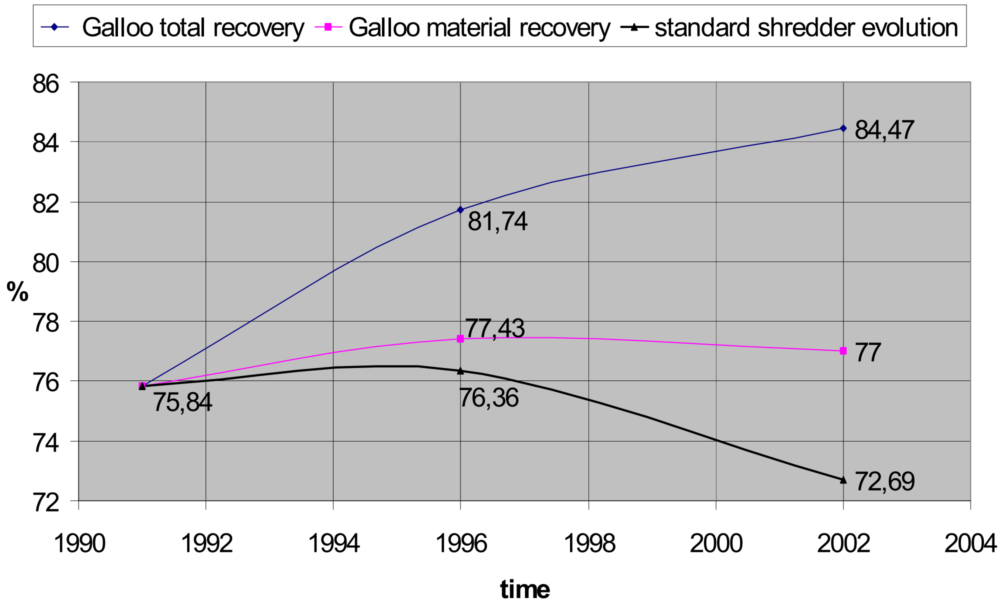


Figure 5.2.1.1.Shredder and post-shredder recovery rate in three different technology development stages. (Ref. 2, 20)

Ref. weight (input)	Ferrous metal	Non-ferrous metal	**Total metals**	Plastics: PP+PE And poly-styrene's	RDF (energy cement kiln)	Tires (energy cement kiln)	Landfill	**Total %**
164 024	68.18	5.43	73.61	3.39	4.00	3.47	15.53	100

Figure 5.2.1.2. Specific recovery rates for different material and energy fractions (% weight) for the 201 ELV sample made in 2002. (Ref. 2, 20)

The values in figure 5.2.1.2. correspond to the values in figure 5.2.1.1. in the following way. Material recovery 2002 = total metals + PP + PE + polystyrenes = 77% Total recovery 2002 = material recovery + RDF + Tires = 84.47%

In 10 years, the vehicles recovery of the “standard” shredder techniques falls from about 76% to 73%. This reduction is due to the drop in the ferrous metal content. We can observe that the level of material recovery is kept constant (77%), thanks to plastics recycling at Galloo-Plastics, as compensation to the ferrous recycling decrease. The total recovery of shredded vehicles using the Galloo processes reaches 84.5% (85%, including recovery of the fluids and the battery).

The shredding, plus the post-shredding processes recover 98% of the metal content of the cars (ferrous and non-ferrous). The amount of non-ferrous metals was found to be 5.4%. There has been a significant increase of such materials in vehicles over the last 10-year period.

Galloo-Plastics processes recycle 50% of the total PP and PE amount in the vehicles and extrudate the material into compounded granulates. Most of the Galloo-Plastics products are used in the automobile industry. For example recycled granulate is used in the manufacturing of “shock absorbers” in the bumpers of the new Renault Megane.

5.3. Fichtner study – validation of pre-treatment processes for shredder residues

APME (Association of Plastics Manufacturers in Europe) and VKE (German Association of Plastics Producers) asked the Engineering company Fichtner to compare and evaluate processes in Europe for mechanical pre-treatment of SR. This was done in 1998. The purpose of applying different processes was to separate SR into organic, inorganic and metal fractions (Ref. 3).

In a first phase, twenty known processes (dry and wet) being developed in Europe were compared. Out of this seven (two wet, five dry) were chosen for an in-depth evaluation. The focus was on dry processes, because these processes are believed to be able to run economically with smaller capacity. Within these dry processes, the high-tech processes give products of better quality at higher recovery rate. Investment and treatment costs are however higher compared to low-tech processes.

Best available processes typically incorporate the following steps:

- Sieving
- Pre-grinding
- Metal separation
- Separation of non-ferrous metals
- Grinding
- Sieving and sifting

A treatment plant with a capacity of 30 000 tonnes/year (three shift operation), based on the information describing the most relevant technologies, would result in treatment costs of 120–130 Euro/tonne SR (cost includes investment, labour, energy, material and maintenance, 1998 cost level).

5.4. Shredder residue – skin flotation (APC Project at MBA Polymers Inc. USA)

The background of APC's (American Plastics Council) work at MBA Polymers covers not only automotive but also electrical and electronic (E&E) shredder residues and screens existing dry and wet processing of SR (Ref. 4).

In early plastic-plastic separation pilot plant studies by APC in 1994–1995, it is demonstrated that different plastics (PE, PP, ABS etc.) collected from ELVs by selective manual dismantling often had overlapping densities. The reason for this is the use of various additives including pigments, fillers, and reinforcements.

Using "skin" or "froth" flotation technologies give a possibility to separate these materials despite overlapping densities. Both technologies are based on chemical surface properties of respective materials. In both the "skin" and "froth" flotation technologies, surface cleaning is applied prior to flotation. "Froth" flotation is using an air stream blown through water affecting material surfaces differently. Air bubbles are attached to the surface pending surface properties (regarding float/sink). "Skin" flotation is using a wetting agent also affecting material surfaces differently (regarding float/sink). However, these technologies need to be more developed: laboratory scale measurements of surface chemistry are needed to adjust the process, larger scale evaluation to separate rubber from plastics is needed.

Preliminary work has demonstrated that a combination of density separation methods with "skin" or "froth" flotation separation methods would enhance the recovery of engineering plastics from shredder residue. Large-scale demonstration defining potential to separate main plastic families like ABS, PC, PP and PU has shown promising results.

Preliminary economic calculations have been assessed for a 10 000 tonnes/ month plant. Information about the shredder composition was collected from a special study, which investigated different types of SR: conventional mixed streams as well as only automotive. Treatment costs of SR have been roughly calculated to 50 Euro/tonne at large throughputs.

Presently there are no ongoing R&D activities on automotive/appliance shredder residue treatment in the United States. The reasons for this is a regulatory barrier due to content of PCB (polychlorinated biphenyl) frequently found in SR.

5.5. Mutabor treatment of shredder light fluff

Mutabor GmbH, Ueckermande (North East Germany) has developed a process for treatment of shredder light fluff (Ref. 5). The resulting material fractions consist of magnetic and non-magnetic materials, which are recycled, and a fuel product, which is used at Scandinavian cement industry (Scancem) as a fuel in their cement kiln. Plastic packaging waste is added in the process to increase energy content and to decrease the potential problematic with high metal content in the fuel. Inorganic materials are not removed thus becoming a part of the final cement product.

Technology description, main steps:

- Magnetic separation
- Adding of other plastics waste (from the packaging sector) plus residues from wire production
- Magnetic separation
- Homogenising and mixing
- Crushing (15 mm sieve)
- Magnetic separation
- Eddy current separation
- Grinding (8 mm sieve)
- Sieving of fuel fraction <6 mm, larger fractions go back to crushing step

17 employees run a 10 tonnes/hour plant at Ueckermonde. Investment cost for the plant is approximately 5 million Euros, partly funded by the State of Brandenburg in Germany. Small-scale test has been successful while large scale trials are pending. Expected gate-fee, charged by the operator for treatment, will be around 95 Euro/tonne SR.

5.6. Salyp mechanical process for material extraction

Salyp has concluded a licensing agreement with the Argonne National Laboratory (University of Chicago - Department of Energy) concerning a technology for the recycling of the plastic fraction present in automobile shredder residue (ASR) (Ref. 19).

With this technology – at laboratory scale – ASR is initially separated into three different streams, two of which contain plastics. See under process description later in the text. One of these streams is the contaminated polyurethane foam coming from e.g. car seats. In a subsequent process this foam is cleaned to a potentially reusable quality. A second stream contains hard plastics and elastomers. Salyp intends to offer a mechanical recycling technology to extract and recycle these plastics.

The two basic steps of the process are separation and pelletisation (production of pellets) of the sorted softened chip in a stamping press. The separation mode operates on differential softening and adhesion behaviour of those plastics contained in ASR when subjected to heat (infrared heating device) and pressed through rolls. All thermoplastics demonstrate a physical change when heated. The intensity of the change depends upon temperature and polymer types. The plastics are not heated above their typical melting point but to a point just below it: the softening temperature. The specific properties of softened plastics (surface adhesion/surface softness) are then used for a mechanical separation. The process yields dry plastics pellets that carry no thermal degradation.

The focus of current developments is to examine the range of the shredding system with changing parameters and an input of various kinds of plastics. The surface contamination effects, the process selectivity, the product quality, the range of properties obtained and the ability of the process to be up-scaled remain to be tackled.

Process description: Input ASR (more info about the process can be found at http://www.salypnet.com/p01o1110.htm).

First separation:
The ASR is separated into four different sizes a double-stacked drum. The 'larges' (pieces in excess of 38 mm) are then treated further in order to extract the PU-foam.

First output:
- Small particles: fractions less than 6 mm with a very high iron oxide content: a perfect raw material, which can be used in the cement industry to produce 'clinker'.
- Plastics rich: fractions over 6 mm which mainly consist of plastics (not PU-foam) as well as wood, stones, glass, fibres, dirt, etc.
- Dirty PU-foam: pieces of PU-foam in excess of 50 mm. These are very dirty with oil, dust, bacteria, etc. and need to be cleaned.

Preparation, cleaning and second separation:
In this step only the two plastics fractions above are further treated. After shredding the large pieces of plastics are cleaned and separated for the second time using air classification. The dirty PU-foam is cleaned in a unique machine able to recycle dirty PU-foam out of ASR into clean foam flakes.

Second output:
- Mixed plastics: a mixture of different sorts of cleaned plastics chips.
- Clean foam: clean foam flakes.
- förmodligen även visst skräp till landfill?

Sorting:
The key part of the Salyp plastics recycling process is the sorting of all the different plastic chips by type. After they have been through the wet zone, the plastic chips go to an infrared rotary drum, where they are rapidly dried and heated. They are then ready to be sorted mechanically, based on the thermo-elasticity of plastics.

Finishing:
PU-foam is finished by baling the foam flakes or by powdering the foam flakes into powder.

Final output:

- Purified plastic pellets: ready for re-use in high-end applications.
- PU foam flakes: ready for re-use.
- PU foam powder: ready for re-use into high-end applications in a mixture of 15% recycled and 85% virgin product.

The estimated market prices for recycled plastics (cleaned, sorted by family and pelletised) are approx. 0.4 Euro/kg, for foam flakes? (sorted and cleaned) 0.35 Euro/kg, and for foam powder 1.0 Euro/kg.

Salyp's aim is to extract up to 70% of the value potential in ASR. An average ELV weighs approx. 1000 kg, of which 75% (i.e. 750 kg) is metal and the remaining 25% (i.e. 250 kg) ASR. The average content of ASR is presented in Figure 5.6.1, and the potential market price of recycled plastics from ELVs in Figure 5.6.2.

Small particles	44%	110 kg
Plastics	31%	77.5 kg
PU foam	5%	12.5 kg
Fibres	10%	25 kg
Rest	10%	25 kg

Figure 5.6.1. Average content of ASR (automotive shredder residues) (Ref. 19)

Indicative market price	Value per ELV
Plastics	31 Euro
PU-foam flakes	4.4 Euro
PU-foam powder	12.5 Euro

Figure 5.6.2. Market prices for recycled plastics from ELVs.

6. Trends affecting the shredder industry and its development

6.1. Metal content is decreasing in new cars

Diminishing returns on steel and iron are the result from less ferrous metals usage in cars and an increase in plastics applications.

Furthermore, an increased amount of galvanized steel for bodywork applications is affecting the value of the scrap. Zinc is vaporised in the metal melting process and is collected in filters. These filters need to be regenerated in order to recover the zinc. Depending on the zinc market price this is a cost or revenue for the metal recycling company (Ref. 7).

Another effect influencing the metal supply in Europe is that many ELVs are exported to Eastern Europe and some to countries where dismantling schemes are financially supported by national or local authorities. Since treatment cost is lower in East Europe as well as in subsidised facilities this situation has distorted the economic conditions and reduced the amount of material passing through the installed shredding capacity.

6.2. Dismantling in order to improve the metal quality out from shredders and to reduce the SR fraction

Shredding of end-of-life vehicles is the most common way to dispose of these products. Dismantling of parts and their reuse is well known and common, e.g. for several parts of the engine, transmission etc. Concerning plastic parts of the ELV, recycling remains a future option but deserves careful assessment. Comprehensive dismantling schemes and trials focussing on plastics have been carried through in a number of European countries (Ref. 11).

The reason behind shredder oriented dismantling is to increase the quality and the value of the metallic output of the shredder, reducing hazardous materials in the residues and last but not least reducing the total amount of residues going to landfill (Ref.12).

Shredder-oriented dismantling would comprise:

- removal of copper- and chlorine-containing parts to ensure a specific quality for materials recycling and energy recovery.
- draining of the fluids and/or removal of fluid-containing components to make shredder light fraction more resistant to leaching.
- stripping the cars of large polymer components to reduce the quantity of shredder light fraction.

Copper-containing components are dismantled only in a few cases, although the copper content is one of the main sources for deterioration of steel properties in material recycling. EU DG XII supported work has started to imaging solutions for recovering larger quantities of copper from electrical motors via the “crushable core electrical motor” design for recycling route.

Work has been conducted in North Rhein Westfalen, Germany, in an attempt to predict the evolution of the quantities of light fraction residues generated by ELV as a function of rate of part dismantling, and age of the cars (Ref. 8), see Figure 6.2.1.

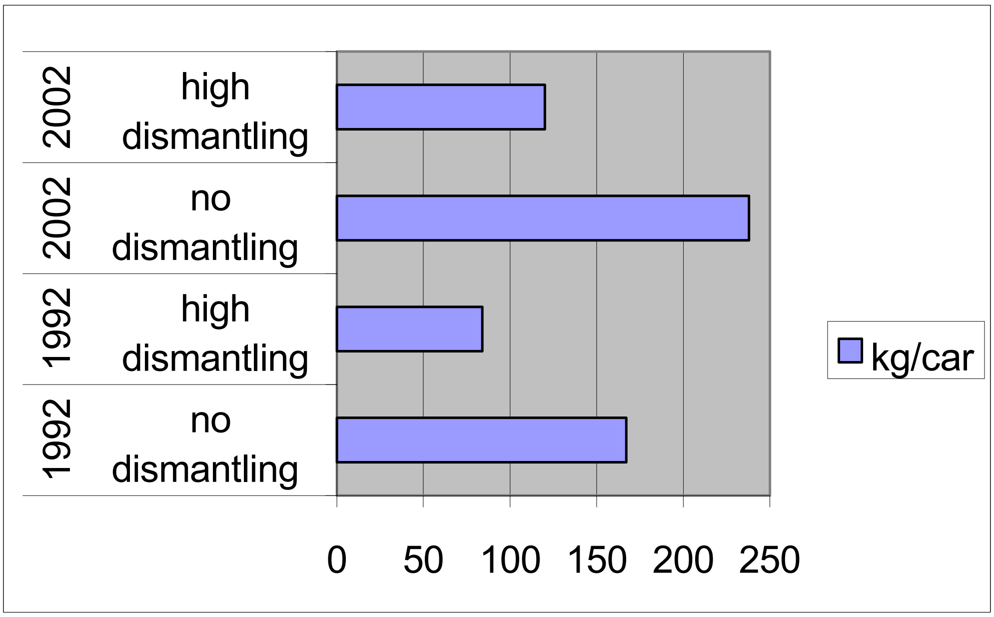


Figure 6.2.1. Estimated shredder light fraction residues (amount per car) as a function of dismantling rate for ELVs 1992 (simulation) and 2002 (trial) (Ref. 8)

As long as the fees for landfill are as low as present, no change of the present situation and no shredder-oriented dismantling can be expected.

The consequence of more polymers in cars and consequently more SR is an increasing pressure on the economic margins of the shredder operation.

6.3. Automated sorting and treatment of shredder residues

Increasing efforts is also put into research how to further sort shredder residues. These efforts have several goals. Main driver is to increase the metal recycling level of the shredder operation and following steps. In additions, sorting of the SR fraction will facilitate plastic recycling and recycling of other fractions as minerals and rubber. Last but not least, fractions can be tailored for use as fuel in combustion processes. As a consequence the amount of residues going to land fill will also decrease (Ref. 15, 17). A good example of efforts in this direction is development of the Galloo SRTL line (see Section 4.2).

To be able to cope with the increasing amount of polymeric material in cars and requirements of environmentally friendly disposal and sustainability, conversion in the shredding process of mainly polymers into a potentially valuable fraction will be required. The polymer parts of ELV are forming up to 15 mass-% of the total ELV at present, and this rate will increase even more in the near future.

7. Economics of shredder operations and SR treatment and disposal

7.1. Operating costs of a shredding operation

The revenue of a shredding operation will depend upon the purchased price of the car wreck and of other feed, specific operation, labour costs, cost of disposal, and value of the ultimate Fe and non ferrous fractions, which are very much fluctuating as any commodity does.

The "EU average" shredder operating cost is estimated to 20–25 Euro/tonne. Operating cost includes investment, labour, energy, material and maintenance.

7.2. Cost for landfill

Shredder residues, especially ASR, are normally disposed to landfills all over Europe. There are regional differences in the costs as well as in the environmental standards of the landfills. Presently in Europe it is in the range 20 - 170 Euro/tonne. Depending of the location of the landfill in each country there are also large cost differences. (Ref. 13, 16)

Cost of landfill is not high enough to stimulate further treatment of the SR, for example, to separate the “cleaner” and more calorific fractions to be turned into an alternative fuel.

7.3. Pre-treatment costs for SR

According to Holderbank (Swiss shredder company), the total investment cost for a wet process SR treatment unit, 50 000 tonnes/year, is in the range of 5 million Euro (Ref. 18). The operating cost is 50 Euro/tonne. Operating cost includes investment, labour, energy, material and maintenance. For a dry process the investment would be 3 million Euros.

APME (Association of Plastics Manufacturers in Europe) and VKE (German Association of Plastics Producers) commissioned the Engineering company Fichtner to make a study to compare and validate processes in Europe for mechanical pre-treatment of SR (see also Section 4.3). A treatment plant with a capacity of 30 000 tonnes/year (three shift operation), based on the information describing the most relevant technologies, would result in operating cost of 120–130 Euro/tonne SR (operating cost includes investment, labour, energy, material and maintenance).

The high uncertainties in these calculations are reflected in the wide variation of the results.

7.4. Comparison of land filling costs and MSW (municipal waste) co-incineration

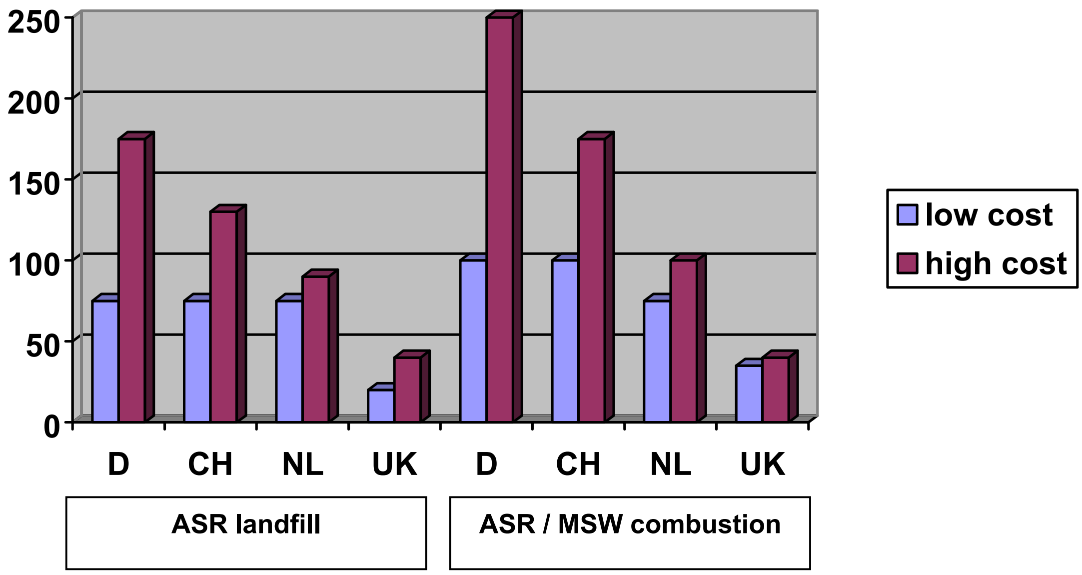


Table 7.4.1. Cost in Euro for ASR to landfill and combustion in four European countries: D= Germany, CH=Switzerland, NL=the Netherlands and UK= United Kingdom. High and low level is indicated in Euro/tonne (Ref. 13, 16).

Cost for SR co-combustion in Sweden during 1998 estimated in the ECRIS project range between 22–32 Euros per tonne SR (Ref. 9). The SR underwent treatment before co-combustion. ECRIS (Ecological car recycling in Scandinavia) was a recycling project run in Sweden between 1994-98. It was initiated by Volvo Cars. The project engaged several actors in the ELV recycling chain.

SR-pyrolysis using Siemens technology shows promising. For a commercial plant for MSWI (municipal waste incineration mixed with SR) with a capacity of 150 000 tonnes/year, costs are estimated to be approximately 150 Euro/tonne (Ref.10).

According to the information of BIR, there are possibilities to treat residual SLF (shredder light fraction) in Northrhine-Westfalia, Germany, through pyrolysis (planned by RAG). Cost is estimated to 250–500 Euro/tonne.

The cost for landfill is generally lower than for ASR/MSW combustion. In countries where the MSW combustion is wide spread it is still an option that can be utilized without large investments. On the other hand the political pressure against shredder residue incineration in some countries is high.

7.5. Cost for recycling of plastic materials

A number of processes are designed specially to recover plastics or plastics are recovered as a step in a larger process also recovering other materials etc. Example of such processes are mentioned and explained in Section 5.

It is difficult to assess the real cost for recovery of plastics. One reason is that plastics often are recovered as a part of a large process with many steps. In addition manufacturers and material recyclers are not to keen on giving specific cost estimations of their specific processes. However looking closer at Galloo and Salyp recycling processes gives some information about the economy of these processes, see also Sections 5.2 and 5.6.

Today polyolefin's (PP + PE) are recovered by the Galloo SRTL process. In addition, a continuous production of polystyrenes granulates started in 2002. Approximately 10% of the output of the SRTL is plastics of which the majority is polyolefin's. Further improvements are being made to recover all the thermoplastics such as ABS, PA, PC, etc.

The polyolefin's are transformed by extrusion into ready to use compounded granulates, which are sold to plastic moulding industry (production capacity of compounded granulates, 2002: 18 000 tonnes/year) Galloo-Plastics processes recycle 50 % of the total PP and PE amount in the vehicles and extrude the material into compounded granulates. Most of the Galloo-Plastics products are used in the automobile industry. For example recycled granulate is used in the manufacturing of “shock absorbers” in the bumpers of the new Renault Megane.

The total cost of the SRTL process is estimated at around Euro 25 /tonne SR. The cost includes investment, labour, energy, material and maintenance. This gives a cost for the plastic fraction (10% of the SR) that equals 0.25 Euro/kg. This cost does not include cost for plastic process, i.e., granulation and production of plastic pellets.

The estimated market price for recycled polyolefin's (cleaned, sorted by family and transformed into pellets) is approx. 0.4 Euro/kg, for PUR foam flakes (sorted and cleaned) 0.35 Euro/kg and for PUR foam powder 1.0 Euro/kg (Ref. 19). This indirectly indicates the maximal process cost level for commercial plastic recycling.

8. Conclusions

The shredder is and will remain a major process step in the recovery route of ELVs. The shredder will also treat other scrap as white and brown goods as well as mixed metallic scrap from households (bicycles, garden tools etc.).

The shredder was first developed to recover ferrous and non-ferrous metal from scrap cars and other goods. The purity and quality of these respective fractions are still subject to research.

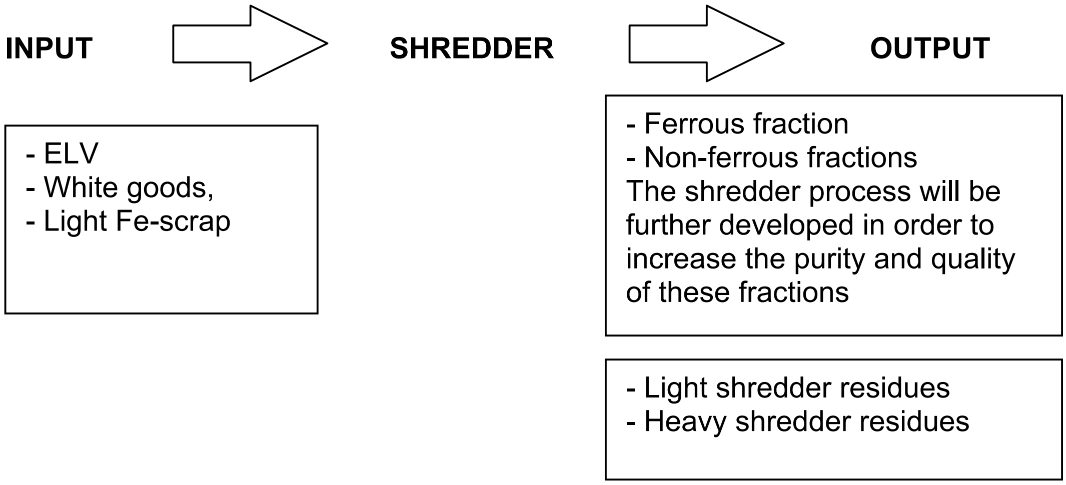


Figure 8.1. Input and output of a typical shredder operation

Increasing efforts is also put into research how to further sorting and preparation of shredder residues. This is particularly important since the content of plastic and rubber material continues to increase in cars.

These efforts have several goals. The main reason is to increase the metal recycling level of the shredder operation and following steps. Still today the SR fraction continues metal fractions, which can be sorted out by various methods.

In addition, sorting of the SR fraction will facilitate plastic recycling and recycling of other fractions like minerals and rubber. Last but not least fractions can be tailored for use as fuel in combustion processes. As a consequence the amount of residues going to land fill will also decrease. Good examples of processes to sort the SR fraction can be found in Section 5 of this report.

9. Acronyms, abbreviations and definitions

APME:
Association of Plastics Manufacturers in Europe

ASR, SR, (A)SR:
ASR, Automotive Shredder Residues. SR, Shredder residues.

BIR:
Bureau international de la récupération, the International body for recycling industries.

Chemical feedstock:
Source of raw material, for chemical processes capable of producing the building blocs of organic chemistry.

Depollution:
Removing from the vehicles substances hazardous to the environment including fluids, battery and pyrotechnic devices.

EfW:
Energy from Waste facilities (Municipal Solid Waste Incineration)

ELV:
End-of-life vehicles

Energy recovery:
Recovery of energy (heat) from combustion as fossil fuel substitute (such as oil or coal) or from mass waste combustors (such as municipal waste incinerators).

Hulk:
ELV which has passed through a depollution and dismantling process.

HWI:
Hazardous Waste Incinerator

Material Recycling:
Any recovery activity as above except energy recovery: it includes mechanical recycling and chemical / feedstock recycling

MSW, MSWI, MSWC:
Municipal Solid Waste/Municipal Solid Waste Incineration/Municipal Solid Waste Combustor.

Recovery:
Treatment whereby materials or energy are obtained for a new utilization cycle.

Reuse:
Product reintroduced in a new utilization cycle for its original purpose or a new one.

Treatment of ELV:
Storage, depollution by removal of fluids, batteries, hazardous materials, fuel, dismantling of parts, shredding and metal separation.

10. References

(Ref. 1) G. Sciberras, 1999. Plastic sorting technologies. Project SUP'RB, which is the acronym for a jointed R&D project carried by six industrial partners: CFF, GALLOO, ELF ATOCHEM, HUTCHINSON, GIFAM and RENAULT. Identiplast, Brussels.

(Ref 2) Olivier Francois (Group Galloo Recycling, Belgium), 2003. Mass-Balance in Post-Shredding Technology: Results of a Trial Based on the Shredding of 201 ELVs – A Joint Work of Galloo, PSA and Renault. Recycling '03 Geneva, March 12-14, 2003.

(Ref. 3) Fichtner Engineering Company, Germany, 1998. Validation of pre-treatment processes for shredder residues. A study commissioned by APME, Brussels.

(Ref. 4) Anonymous, 1999. Shredder residue - Froth flotation. Abstract of APC Project, MBA, Ca, US.

(Ref. 5) Anonymous, 1997. Mutabor Treatment of Shredder Light Fluff. EUWID Recycling: 34 (19. Aug), p2-4.

(Ref. 6) Autoverwertung Ostschweiz (AVO), 1998. ASR characterization – Analysis of ASR fraction from AVO, Switzerland.

(Ref. 7) Anonymous, 1997. Recycling of zinc and lead containing dusts from the electric arc furnace Brite Euram project 5201. Organisation Brite Euram, Brussels.

(Ref. 8) J. Woidasky, U. Braunmiller and T. Hirth (Fraunhofer-Institut, Germany), 1999. Shredder-Oriented Dismantling And Shredder Lightweight Fraction. Recycling '99 Proceedings, Vol III, p. III 345-350. Geneva.

(Ref. 9) U. Liljenroth, 1999. ECRIS project – energy recovery report. Volvo Car Corporation, Gothenburg.

(Ref. 10) M. Christill, 1998. SR-Pyrolysis Using Schwel/Brenn-technology. Siemens-KWU, Germany.

(Ref 11) P. Groenewegen and F. den Hond, 1991. Technological innovation in the plastics industry and its influence on the environmental problems on plastic waste. DRAFT Report Appendix to study, Sast project N°7, study N°3, C 9. Free University of Amsterdam, Amsterdam.

(Ref 12) A. Nijkerk, 1998. New development in shredder technology. Recycling International, Oct., p.20-29.

(Ref 13) J. Henton, ICI Technology, 1998. ASR treatment. Thematic Network, Energy Recovery Group meeting, Lyon 28 Jan. 1998.

(Ref 14) Michael Fischer (American Plastics Council, US) and Frank Mark (Dow Europe, Horgen, CH), 1998. The Role of Plastics in Automotive Shredder Residue Characterization and Environmental Assessment. Organisation. APME report, Brussels.

(Ref 15) L. Bontoux and F. Leone, 1997. IPTS, the legal definitions of waste and their impact on waste management in Europe. Institute for Prospective Technological Studies, European Commission, Joint Research Center Sevilla, Sevilla.

(Ref 16) F.E. Mark, 1998. Thermal recovery of (A)SR – A way forward to ELVs management. BHM, 143. Jg., Heft 1. Germany.

(Ref 17) O. Large and S. Zariatti , SOFIVAL, 1999. New Automobile Shredder Residue Recycling Processes. in Recycling ’99 Proceedings, Vol II, p. II 265-270. Geneva.

(Ref 18) J.P. Degré (Holderbank, CH), 1998. “Recovery of (A)SR – (Automotive) Shredder Residue. Report. Schweiz.

(Ref 19) Salyp, 2003. Recycling ASR. http://www.salypnet.com/p01o1110.htm

(Ref 20) APME/EUCAR, 2003. Plastics in End-of-Life Vehicles. http://www.plastics-in-elv.org/

(Ref 21) European Commission - DG XII, and a Consortium of Automotive companies, Plastics resin producers, Dismantlers, Shredders, Recyclers, Molders of plastics parts, Energy users and Research Institutes, 1999. "European Information Network for the development of Eco-efficient Treatment of End of Life Vehicles with emphasis on Plastics". Final report

(Ref 22) Shredding and media separation, 2004, BIR, Bureau of International Recycling, website, http://www.bir.org/

(Ref 23) New Automobile Shredder Residue Recycling Processes. O. Large, S. Zariatti (Sofival), in Recycle'99 Congress Proceedings, 1999, vol II, pp. 265-270

(Ref 24) Montello process, Italy, 2002, Plastics in ELV website http://www.plastics-in-elv.org/

Appendix E

Post-Shredder Treatment Technologies

Abstract

This study was carried out in the end of 2002 as a pre-study in the project "Resource-saving design" carried out at CPM. The aim of this study has been to map the different technologies for treatment of Shredder Residues (SR) and to make an assessment of which of the technologies that will be the most probable to be used in Europe in the future.

Seven groups of technologies were identified:

- Co-combustion with Municipal Solid Waste (MSW)
- Production of cement
- Production of iron and steel
- Material recycling of polymers
- Material recycling of non-ferrous metals
- Chemical conversion
- Other technologies for energy recovery

Since the prerequisites and legislation differ largely from one country to another, it is difficult to predict which of these technologies will be the one or ones used in the future. It is probable that a combination of technologies will be the answer. According to ACEA, technologies that involve pyrolysis of organic material seem to be a promising solution.

Sammanfattning

Den här studien genomfördes i slutet av 2002 som en förstudie i projektet "Resursbevarande konstruktion", som utförs genom CPM. Syftet med den här studien har varit att kartlägga olika teknologier för behandling av fragmenteringsrester och att göra en bedömning av vilken/vilka av teknologierna som troligen kommer att användas i Europa i framtiden.

Sju grupper teknologier har identifierats:

- Förbränning med kommunalt avfall
- Cementproduktion
- Järn- och stålproduktion
- Materialåtervinning av polymerer
- Materialåtervinning av icke-magnetiska metaller
- Kemisk upparbetning
- Övriga energiutvinningsmetoder

Eftersom förutsättningar och lagstiftning skiljer sig mycket mellan olika länder, är det svår att förutsäga vilken eller vilka av teknologierna som kommer att användas i framtiden. Det är troligt att en kombination av teknoliger blir svaret. Enligt ACEA verkar teknologier som inkluderar förgasning av organiska material en lovande lösning.

Acronyms and abbreviations

ASR – Automotive Shredder Residues
CPM – Chalmers Competence Centre in Environmental Assessment of Product and Material Systems

ELV – End of Life Vehicle
MSW – Municipal Solid Waste
HW – Hazardous waste
PST – Post-Shredder Treatment
SR – Shredder Residues

Contents

1. Introduction

Background

In the European Union approximately 5.5 million cars are scrapped each year. The EU Directive 2000/53/EG has set forward requirements on how much of this scrap that has to be reused or recycled, how much that can be incinerated for energy recovery, and the maximum amount that can be put to landfill by the years 2006 and 2015. This implies that car manufacturers have to improve the recoverability and recyclability rates for passenger cars.

The issue has been addressed by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material Systems) where a project called “Resource-saving design” was initiated in cooperation with ABB, Bombardier, SAAB, AB Volvo and Volvo Car Corporation in the end of 2002. This study is a pre-study in that project.

Purpose

The purpose of this study is to map the different technologies for treatment of Shredder Residues (SR). The shredding plants in Sweden are to be mapped out, as well as the market actors in Europe. An assessment of which technologies are the most likely to be used in the future is also included.

Objectives

The objective is a description of the present situation for post-shredder treatment (PST), which will form a basis for further discussion about PST-technologies and Design for Recycling in the project ”Resource-saving design”.

Scope

The study comprises a description of the most known technologies for PST, a mapping of the Swedish shredding plants and the market actors in Europe, and an assessment of which technologies that are the most likely to be used in the future. Also included in the assignment, is production of a presentation material that describes end-of-life treatment and shredding of a passenger car.

2. Methodology

Information has been searched for in literature and through personal contacts. Some information is classified, in these cases data has been searched for from the original sources. A visit to the Stena Fragmentering plant in Halmstad has given an insight in shredder residue sorting technologies and in the complexity of the problems with shredder residue treatment. Also, Ulf Liljenroth at WSP Environmental has provided information about PST.

3. Results

End-of-life treatment of passenger cars

The dismantler starts with drainage of the passenger car, which means that the car is emptied of its fluids such as oil, petrol, washer fluid, brake fluid, glycol and cooling agents. After the drainage, the starting battery, the counter weights, air bags and components containing mercury are dismantled.

Batteries and lead are recycled whereas components containing mercury are sent to deposit. Liquids that cannot be reused, especially motor oil are sent to companies with special permits for energy recycling of these types of substances.

The catalyst, tyres and other components that can be reused are dismantled. If the car has parts that can be sold, these parts are stored. Some parts are reconditioned before being sold again as spare parts. The storage is computerised with data on age and origin for each component. There are special rules for components that are crucial from a safety point of view.

A joint database system makes it possible for the dismantler to find an article in storage at any other dismantling company if he or she does not have the article in storage.

Also materials such as glass and sometimes also plastics are dismantled from the car, starting in the end of April 2002. These materials will be recycled as materials in new products, sometimes in new car components.

The dismantled cars are then sent to a shredding plant. At the shredding plant the cars are cut into smaller pieces and fed onto a conveyor belt into the shredder. In the shredder, pieces are sorted with the help of magnets, air currents, baths and manually. There are three main materials outflows from the shredder: ferrous metals, non-ferrous metals and Shredder Residues (SR). Most of the SR is put to landfill today.

Post-shredder treatment technologies

In order to minimize the amount of SR sent to landfill, new technologies have been developed and tested, some even run in full-scale, to treat shredder residues.

1. Co-combustion with MSW

Co-combustion with Municipal Solid Waste with energy recovery is a method that has been used in full scale in several countries for some years. Light and heavy fraction SR can be mixed into the MSW with up to 20-30% of fuel weight.

An increase in metal contents in flue gas, fly ash and residues can be seen. In the flue gas there is an increase in the content of arsenic, lead and zinc, which is reduced in the flue gas cleaning. In the boiler ash and residues there is an increase of zinc, copper, antimony, cobalt, nickel and lead.

The co-combustion technology has the advantage in that it can be done without further modifications of the MSW combustion plant. This gives it an economical advantage compared to other alternatives.

This technology has mainly been used in Germany, France and Switzerland. The gate fee ranges from 30 EURO/ton to 250 EURO/ton.

2. Production of cement

SR can also be used as an energy and material source in cement production. The SR often has a content of metals that is too high and it has to be refined before usage. Some different techniques have been tested for refinement: dry separation (Comet Sambre, Belgium), wet separation by flotation (Chapparal Steel, USA), thermolysis at 500 – 650 degrees C (THIDE, France), or molten slag gasification at high temperature, 1450 degrees C (ScanArc Technology, Austria). The methods that have given the best results are wet separation and molten slag gasification.

Mutabor GmbH has developed another process for refinement of SR light fraction to be used in cement production. The process steps are:

- Magnetic separation
- Adding of other plastic waste from packaging sector and residues from wire production
- Magnetic separation
- Homogenizing
- Crushing
- Magnetic separation
- Eddy current separation

- Grinding
- Sieving

The SR is combusted in a pre-calcinator and thereafter diverted into the kiln.

VALERCO was founded by CFF and VICAT in 1991, and has its own SR pre-treatment. The VALERCO line is made of a riddle, shredder, two over bands and an eddy current separator. The output is mixed with shredded tires and industrial waste before usage in cement industry.

The use of SR in cement industry has one advantage over others in that there is no sludge to be put to landfill after the process. Inorganic matter becomes part of the cement. One problem is that the content of copper often is high, even when refinement of SR has been carried out. Also chlorine contents in SR have to be decreased.

3. Production of iron and steel

In iron and steel production a reducing agent is needed since there may be unwanted iron oxides in the iron ore. This is traditionally done with coke, coal or heavy oil, but tests with mixed plastic packaging waste have been successful. This technology is accepted as material recycling.

Shredder residues, which have been treated mechanically, are blown into the blast furnace. The residues are then converted to hydrogen and carbon monoxide, which react with iron oxide to form metallic iron, carbon dioxide and water. Analyses of pig iron and slag show that they are of same composition as before (no unwanted hazardous substances). The waste gas from the blast preheater contains carbon monoxide, carbon dioxide, nitrogen oxide, sulphur dioxide, hydrogen fluoride, hydrogen chloride and hydrogen bromide. Hydrogen chloride content was somewhat higher than before, probably due to input of PVC.

No increase of the emissions of dust particles, heavy metals, polychlorinated dioxins or furans in the waste gas has been detected. One prerequisite for usage of SR in this way is that it is properly separated (mechanically) before being fed into the blast furnace. Inert material such as metals should be removed so that the organic material content is increased.

At Stahlwerke Bremen, mixed plastic packaging has been used as a reducing agent since 1994. Trials with SR have been conducted in co-operation with Daimler Chrysler and Bregau Institute.

4. Material recycling of polymers

Plastic-plastic separation has been tested in pilot-scale by the American Plastics Council, with froth flotation and electrostatic type process. There have been some problems with overlapping densities due to additives in the plastics: pigments, fillers and reinforcement materials. MBA Polymers Inc.and Recovery Plastics Industry has tested separation of filled PP from ABS in automotive interiors.

The skin flotation process can be described as:

- Surface cleaning
- Skin flotation – similar to froth flotation but using a plasticizer
- Surface chemistry measurements to evaluate additives
- Large-scale evaluation to separate rubber from plastics
- Separation of ABS, PC, PP mm in ASR

Pure automotive SR gives better plastics quality. Combination of froth floatation and density separation methods gives the best results.

The American Plastics Council has worked with MBA Polymers Inc., Recovery Plastics International and Argonne National Laboratories in investigating froth flotation.

5. Material recycling of non-ferrous metals

Material recycling of non-ferrous metals can be done through incineration and melting. Copper, zinc and lead can be recycled this way. However, there is a need for valuable metals in the SR, at least 10-15% copper or other, in order for the technology to be economically viable.

One example of this process is the Reshment technology where copper and iron sludge is extruded from fine ASR and fly ash from other processes with the help of a cyclone. The Reshment process is used, among other places, at MEFOS plant in Luleå, Sweden.

The single largest material recycler of non-ferrous metals in Sweden is Boliden.

6. Chemical conversion

The chemical conversion technology involves gasification of the shredder residue.

This technology is used at SVZ Schwarze Pumpe in Germany. The gasification takes place in a moving bed gasifier. Organic matter is partially oxidized to CO and H2 (the synthesis gas for production of methanol). Non-combustible materials are collected and put to landfill.

Another site where gasification is used is in the Montello process in Italy. SR and iron scraps from the shredder process are fed together into the rotary kiln. The iron scraps mixes the SR, which keeps the SR from overheating in some areas and from sticking to the walls of the kiln. The organic material is gasified and the gas diverted to a post-combustion chamber. The iron is heated, melted and cleaned by the high temperature and used for steel rods and bars for concrete reinforcement. Flue gas from the post combustion chamber is cleaned. Any excess gas from the kiln is used for steam generation or energy recovery.

7. Other technologies for energy recovery

These methods differ from traditional incineration or chemical conversion in that they have only been used in pilot scale and are not as well known and tested as the other technologies for energy recovery. Examples of these technologies are incineration in rotating furnace and fluidised bed or treatment with municipal solid waste in the “Von Roll – RCP” process, where the MSW and SR undergoes pyrolysis, melting, sludge treatment and post-incineration.

An example of technology that has been tested plant is the Schwel/Brenn-process in Germany. The process is of a two-stage type that starts with pyrolysis in a rotary kiln. The pyrolysis gas and residual coke are combusted in the second step. Minerals in the coke are molten and discharged via water bath for granulation. Flue gas is cleaned in multistage system.

Market actors

In Sweden the largest shredding company is the Stena Group, where Stena Fragmentering (Halmstad, 035-22 33 00) has four shredder sites in Sweden, one under construction in Finland and one in Poland. The four sites in Sweden treat approximately 650 000 tons of scrap each year. Other shredding companies in Sweden are Skrotfrag AB (Göteborg, 031-3323990) and Arvamet AB (Skellefteå, 0910-711 770).

BIL Producentansvar Sverige AB (BPS) was founded in May of 1999 with the assignment to support car producers with knowledge about producer responsibility and recycling. BPS is organised under BIL Sweden, the branch organisation for all car producers in Sweden.

Sveriges Bildemonterares Riksförbund (SBR) is a branch organisation for car dismantlers in Sweden. It was founded in 1961. Its objectives are to work towards a sound development of the car dismantling in Sweden and to accomplish an optimised recycling of raw materials and spare parts from cars. SBR is a member of EGARA and ARA.

EGARA - European Group of Automotive Recycling Associations was founded in 1991. It is the European umbrella association for the national associations of automotive recyclers in Europe and represents automotive recyclers in Europe. Their mission is to facilitate and develop the economic activities of European Automotive Recyclers; to stimulate the development of environmentally justified working methods for the companies and to stimulate product and material reuse.

Automotive Recyclers Association (ARA) is an international trade association that since 1943 has “represented an industry dedicated to the efficient removal and reuse of automotive parts, and the safe disposal of inoperable motor vehicles”. The organisation has its office in the U.S.A. It aims to increase the public awareness of the importance of automotive recycling and the recycling industry’s value as a high quality, low cost alternative for the consumer.

Bureau of International Recycling (BIR) is a trade organisation that represents national sectoral federations and approximately 500 recycling companies worldwide. Its goals are to “promote materials recycling and recyclability, thereby conserving natural resources, protecting the environment - and facilitating free trade of recyclables in an environmentally sound manner”. BIR was founded in 1948.

Global Recycling Network (GRN) is a free-access public site dedicated to recycling-related information. Its aim is to provide an electronic information exchange that specializes in the trade of recyclables reclaimed in Municipal Solid Waste (MSW) streams, as well as the marketing of eco-friendly products.

Other projects in the same field

During 1998 through 2001, Stena Gotthard Fragmentering and Volvo Car Corporation carried out a project called Shredder Waste Recycling (LIFE98 ENV/S/476), partly financed by the EU LIFE Environment programme. The aim of the project was to convert shredder waste into a quality assured energy fraction and increase recycling of iron and metals while minimizing the residues to be land filled.

The project shows that the best way to effectively quality assure shredder residues is to de-pollute the waste to be shredded before it arrives at the shredder plants. Without de-pollution of scrap, the shredders in Sweden will receive about 300 kg of mercury and 5 tons of PCB yearly, mixed in the scrap to be shredded.

In the ACEA report “Recycling Infrastructure and Post Shredder Technologies – Final Report” a mapping of different technologies has been carried out. The technologies were assessed according to criteria set up by ACEA, among others the appropriateness of the technologies to handle the type of SR produced in Europe, the cost effectiveness of the technologies, and their ability to produce results which meet the EU Directive’s recycling and recovery targets.

The processes that were proven to be the best according to ACEA were Citron, Ebara, IGEA-Reshment and VW-Sicon. Also remaining under consideration are RPI and Schwarze Pumpe.

The Citron process consists of a rotating furnace into which a mix of SR and iron sludge is fed. The temperature of the furnace is 1200 degrees C. Additional electricity and gas is required for the process. Solid and liquid residues are then extruded and cooled. Solid residues are separated by shredding, sizing and magnetic and eddy current separation. The outputs are 40-50% material that goes to the cement production industry, and the rest is Zn/Fe concentrates, pure Hg, Pb, Cd oxides and K and Na salts.

Ebara is a Japanese company, whose process is called the “Twin-Rec” process. SR can be fed directly, or mixed with other wastes or sludge. The SR is fed into a furnace with a fluidised bed at 500-600 degrees C. Ash is extracted, grinded and mechanically sorted for metals. Sand is extracted and recirculated into the fluidised bed. Further combustion in Vortex vitrifies fine particles at 1450 degrees C. Outputs are steel, copper, aluminium after combustion of the organic content. Granulate is melted (vitrified) for construction industry. 10% of input is sent to landfill, but could probably be processed further for recycling of Zn/Pb. The process generates electricity.

In the Reshment process, used by Swiss IGEA, 53% SR and 47% fly ash from MSW incineration are fed into a small Vortex furnace at 1550 degrees C. Outputs are aluminium, copper, steel, smelted iron/copper, melt granulate for construction industry, Zn/Pb/Cd as to metals industry and gypsum. The process generates electricity.

No information has been found on the SiCon technology other than which the outputs from the process are:

- Granulate – to be used instead of coal or heavy oil in blast furnaces
- Fibre – to be used as a dewatering agent for sewage sludge
- Sand – to be used for secondary smelting of copper, lead, iron and zinc
- Dust/sludge – proposed to be incinerated

RPI (Recovery Plastics International) separates plastics with froth flotation. The process steps are:

- Heavies removal
- Air Aspiration
- Heavy Media
- Granulation
- Materials Washing
- Foams Separation
- Plastics Separation
- Product Drying
- Plastics Pelletizing

The process can handle nearly all types of shredder residues.

The Schwarze Pumpe process is a process where shredder residues and other types of wastes are gasified and converted into methanol to be used as a fuel.

4. Conclusions and recommendations

There are many ongoing activities in order to find solutions to reduce the amount of automotive shredder residues put to landfill. In this study we have found seven groups of technologies, where most technologies include gasification or pyrolysis of organic material in one way or another.

It is difficult to make a prediction on which of these technologies will be the one or ones that are used in the future. The prerequisites, as well as legislation, differ largely from one European country to another. I Southern Europe, there is no need for thermal energy in the same extent as in the Northern Europe. Legislation on what is classified as Hazardous Waste differs from country to country, as well as legislation on what waste can be put to landfill and in which amounts. The most probable scenario for the future is a mixture of technologies and solutions. It is obvious that large-scale solutions are the best from an economical point of view.

According to ACEA, the most promising technologies include technologies for use of SR as reduction agents and production of construction materials, but also technologies for separation of plastics through flotation and production of methanol are considered.

In addition, modularisation and dismantling for reuse or material recycling also needs to be focused upon. Reuse of components is often the best solution from an environmental point of view. Material recycling is also beneficial and dismantling before shredding creates cleaner shredder fractions. These solutions may not be as economically viable as shredding and post-shredder treatment, but may be a necessary measure and complement to shredding since there are indicators that point towards an extended and even more stringent producer responsibility for materials and products in the future.

Data sources that may be useful in the continuation of the project:

- ACEA report
- Conrad Luttrop, KTH
- Handbok för konstruktörer av Stena Gotthard
- Arvamet AB, www.arvamet.se
- Kuusakoski, www.kuusakoski.com
- Stena Fragmentering AB, www.stenametall.com
- European Group of Automotive Recycling Associations, www.egaranet.org
- Sveriges Bilskrotares Riksförbund, www.sbrservice.se
- Boliden, www.boliden.se

- Plastics in ELV, www.plastics-in-elv.org
- Automotive Recyclers Association, www.autorecyc.org
- Bureau of International Recycling, www.bir.org
- Global Recycling Network, www.grn.com

5. References

Literature

ACEA report "Recycling Infrastructure and Post Shredder Technologies – Final Report", June 2002

Graz, proceedings

LIFE98 ENV/S/476 Final report no.1

Personal contacts

Ulf Liljenroth, WSP Environmental

Stanley Johansson, VCC

Nils Hernborg, BSP

Hitomi Cannon, Stena Fragmentering

Jan I Andersson, Stena Fragmentering

Information on the Internet

Plastics in ELV, http://www.plastics-in-elv.org/

EGARA, www.egaranet.org/

Appendix F

Responsible division	Responsible unit	Document type	Confidentiality status	BOMBARDIER TRANSPORTATION
Intercity Trains	CoC DfE			
Prepared		Title	Document state	
2004-08-30 Ylva Larsson		Bombardier Transportation Experiences of EoL treatment of rail vehicles	Released	
Checked				
2004-09-06 Sara Paulsson			3EST 7-3016	
Approved		File name	Revision / Language / Pages	
2004-09-08 Ulrika Lundqvist			1 / en / 1/11	

Bombardier Transportation Experiences of End of Life Treatment of Rail Vehicles

Abstract

This report summarises the information regarding End of Life treatment of rail vehicles that has been gathered in this area the last three years at the Design for Environment department at Bombardier Transportation. The focus is to point out the differences from the automotive industry, this to be able to predict differences in future and probable scenarios for End of Life treatment of rail vehicles in future. The work has been carried out as a part in the Design for Recycling project initiated by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material systems) in the end of 2002.

Customer requirements in the rail industry are similar to the recyclability requirements that are legislated on the automotive industry in the End of Life Vehicle directive. Similar components containing hazardous substances such as mercury, lead, cadmium and fluids need also to be disassembled before the shredding process. But the components do not look the same and they differ in size and location. Rail vehicles are considerable larger in size than automobiles but the volumes of end-of-life rail vehicles are still much less than automobiles per year due to the larger series in the automotive industry. A car model is produced in many more units compared to a rail vehicle model. The lower number of end-of-life rail vehicles makes it more difficult to develop specific dismantling systems and specific material flows for rail vehicles. It is beneficial to coordinate material fractions for recycling and recovery activities and logistics systems with other type of industrial waste. Other major differences between the rail and the automotive sector are the considerable longer life length for rail vehicles which implements a larger reuse of components, the interior refurbishment that takes place, that the owners at end-of-life are not private consumers and that the control of the vehicles is larger. Producer responsibility discussions must take these issues into account.

At end-of-life, the major fraction of the rail vehicles is often shredded and then the recovery routes for the materials are the same as for the automotive waste and other waste at the shredding plant. It is important for all industries to recycle and recover more fractions than the metal fractions. To make this happen the demand to use recycled materials in new production must increase.

Contents

1 Introduction

Background

A Design for Recycling project was initiated by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material systems) in the end of 2002. Participating companies from the transport sector are AB Volvo, Bombardier Transportation, SAAB and Volvo Car Corporation. One of the driving forces behind this project is the ELV directive (2000/53/EC) that sets future requirements on how much of the automotive waste that shall be recycled and recovered and how much of the waste that can be put to landfill at 2006 and 2015. Background for the work is studies e.g. ECRIS (Hernborg, 1998) on how it is possible to increase the recycling and recovery rates for automobiles.

Other studies in the DfR project has been used as background information to this report e.g. reports by Ulf Liljenroth and Caroline Sjöberg about different technologies for treatment of shredder residues and an assessment of which of the technologies that will be most probable to use in Europe in future.

Purpose

The ELV directive does not cover rail vehicles. It is of interest to study how the End of Life (EoL) treatment of rail vehicles differ from EoL treatment of automobiles today, to be able to predict differences in future and probable scenarios for EoL treatment of rail vehicles in future. To identify probable future scenarios will help in determining which design guidelines that are the most relevant to focus at today to facilitate an environmentally sound end-of-life treatment in future.

Objectives

This report summarises the information that has been gathered regarding scrapping methods of rail vehicles the last three years at the DfE department at Bombardier Transportation. The goal is to give a fair description of End of Life treatment of rail vehicles today and point out the differences between EoL treatment of rail vehicles and automobiles.

Methodology

Information has been obtained through personal contacts (telephone interviews and study visits) and by reading reports and published material.

Scope

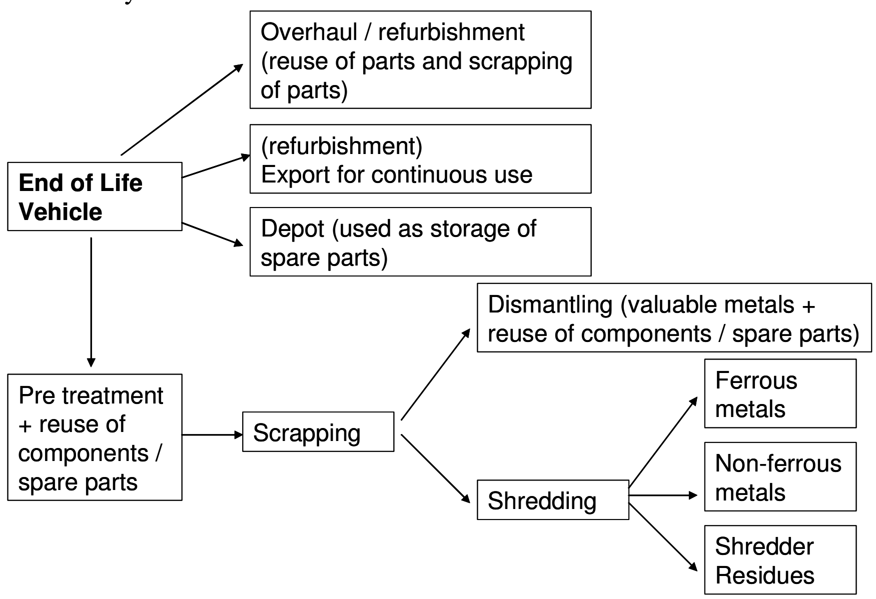
The report shall cover end-of-life treatments of rail vehicles that have come to the Design for Environment department's knowledge the last three years. It also covers analysis and material contents of two modern rail vehicles.

The study does not cover disassembly and shredding techniques.

2 Results

2.1 EoL treatment of rail vehicles (today) in general

This section describes general procedures and options in the EoL treatment of rail vehicles today:



Picture / overview of alternatives in EoL treatment of rail vehicles (Y Larsson, 2004)

In many cases the timing of the determined scrapping/taking out of service is dependant on when a new *vehicle fleet* is being bought in. The life length of the existing fleet has most often been extended with appropriate maintenance, overhaul and refurbishment during the life time. Especially the interior and textiles need refurbishment after a couple of years. Component reuse is frequent since the vehicles often are kept in depot as storage of spare parts a couple of years. To minimize maintenance costs, parts in good condition are often reused e.g. wheels, wear parts, fire extinguishers, bogies, propulsion equipment and engines.

There are examples of rail vehicles left in nature, e.g. dumped at sea, but in absolute most cases legislation, control of the actors and the high metal content imply both appropriate pre-treatment and recycling of the end-of-life vehicles.

In some cases the end-of-life vehicles are refurbished and exported/sold to other operators. This is limited by different track gauge and power supply between countries, but some different standardised systems exists. The end-of-life activities are similar in different European countries (V Mannheim, 2001).

The amount of disassembling prior to shredding varies and the important parameters are plant, tools, infrastructure, costs, beforehand knowledge about the vehicle with respect to composition and material content, waste legislation and network of receiver of a disassembled component. For example, all electric engines that are not directly reused can be sold to a company in Germany that are specialized on the EoL treatment on electric engines and therefore is this company the most cost efficient alternative. Larger copper parts e.g. bars and cables also generate a positive prize at the market and are cost-efficient to disassemble. The method of disassembling varies also due to different previous experiences, choice of equipment and beforehand knowledge of product. Manual disassembling and to cut apart pieces with big scissors are the dominating methods (R Larsson, 2001).

All fluids are recovered and components containing hazardous substances, such as mercury, lead and cadmium, are removed prior to shredding (e.g. batteries, fluorescent lamps, thermometers, relays, capacitors and other electrical equipment) (Å Eriksson, 2002).

Too thick parts (e.g. the couplers) for the shredding process are removed and decreased in size with manual methods (N Habashian, 2002).

The metals are recovered after the shredding process but other materials are often put to landfill, even though the Landfill directive (1991/31/EC) has resulted in national strategies to reduce the amount of waste that is landfilled. In Sweden this has resulted in a prohibition to landfill combustible waste from first of January 2002 and a prohibition to landfill organic waste will be implemented 2005 (Y Larsson, 2001).

The rail vehicle manufacturer Alstom and the environmental consultant Agimus in Germany have carried out a demonstration project of the Hamburger underground DT 4.4. It included the calculation of the environmental effects and costs of the recycling. The vehicle was dismantled into all its components with the help of the design drawings and parts lists available. Each component part was recorded by terms of material, weight and type of installation. Disassembly times, personnel required and energy and materials consumption were denoted and all these data were collected in a database (Internet reference, 2003).

An Environmental Product Declaration has been made for Hamburger Hochbahn AG DT 4.5. The EPD states that thanks to the complete disassembly procedure developed for the DT 4.4, it was possible to derive measures for a better dismountability of the DT 4.5. The recycling rate has increased by 3.5 points from 90.8 for DT 4.4 to 94.3 % by weight for DT 4.5 (EPD, 2002).

2.2 Market actors

Sweden

While there are many small plants all over Sweden where cars can be scrapped it is needed more space and special equipment to scrap rail vehicles, e.g. big hoisting cranes and big scissors to cut the carbody frame down. Shredding plants that the Design for Environment department knows have scrapped entire rail vehicles are **Stena** in Huddinge and in Hallstahammar.

Picture of an old Stockholm metro car in scrapping activity at Stena, Huddinge (Y Larsson, 2002)

There is also a company that started specialized on handling EoL rail vehicles containing asbestos; **O Hallquist Återvinning AB** in Nykroppa. Today all asbestos have been replaced in earlier refurbishment activities and the company scraps old rail vehicles such as locomotives, freight cars and passenger cars.

Picture of a passenger car in scrapping activity at O Hallquist Återvinning AB (M Nilsson, 2004)

Europe

In Central Europe where the replacements of vehicle fleets often are bigger and more concentrated, specialization of different plants is more common. One example of this is a company in Germany that is specialized in scrapping old Deutchebahn locomotives, Fa. Peter Bender in Leverkusen.

2.3 Material content in modern rail vehicles vs. automobile

Material content, % wt.	**Bombardier Transportation Inter regional train Regina (2-car 115 ton) [EPD, 2001 and ENVIRA database]**	**Bombardier Transportation Stockholm metro car (3-car 70 ton) [EPD, 1999 and ENVIRA database]**	**Volvo automobile, material information in ECRIS (1 ton) [ECRIS, 1998]**
Construction metals (steel, iron)	66	68	72
Construction metals (aluminium)	12	13	5
Hazardous/rare/heavy metals (copper, lead, zink, cadmium)	4	3	3
Noble metals and circuit boards	0,1	0,3	No info
Plastics (thermosets, thermoplastics)	4	2	10
Rubbers	1	2	5
Wood, plywood, cloth, leather	5	3	No info
Composites	1	2	No info
Glass	2	3	2
Other (ceramics, insulation, adhesives, fluids)	5	4	3

Table of material content (%wt.) of two rail vehicles and one automobile

Bombardier Transportation's Design for Environment department has developed an Inventory Tool, an Excel tool, designed to include the material data of all products (system, components and parts) that belongs to a vehicle. The Inventory Tool is filled in by designers and suppliers and imported to the Access database ENVIRA. The database contains material data and environmental data per each project and is used to report e.g. materials in quantities used in the vehicle and the environmental performance of the vehicle.

2.4 General differences and similarities between EoL treatment of rail vehicles vs. automobiles

Differences	Similarities
• *Control:* The operators/owners know exactly where the rail vehicles are. The business is state-owned or run by big private operators the end-of-life treatment is controlled by laws. Private consumers are not involved and there is little risk that a rail vehicle is simply left in nature. • *Number of end-of-life vehicles:* Due to the larger number of automobiles scrapped per year, the waste volumes of rail vehicles are smaller than the volumes of automobiles. According to ELV directive (2000/53/EC) between 8 and 9 million tons of waste are related to EoL automobiles. No corresponding figure has been found for rail vehicles, but it is considerable smaller. • *Simplicity:* The larger series of automobiles and the producer responsibility facilitate an optimization of the EoL treatment for automobiles. • *Life length:* In practice, automobiles have less than half the service life compared to rail vehicles. DfR strategies must therefore be more long-termed chosen for rail vehicles. • *Size/weight:* Automobiles are much smaller and are therefore easier and cheaper to scrap • *Material:* The parts that need to be disassembled prior to shredding do not look the same and they differ in size and location. General material content has similarities but is not exactly the same. See table in section 2.3. • *Legal producer responsibility:* The automotive industry has a legislated producer responsibility in EC; the ELV directive is restricting both what is built into the automobiles and recycling rates are also specified in the directive.	• *Pre-treatment:* Removal of components containing similar hazardous substances is needed (e.g. fluids, batteries and components containing heavy metals). • *Waste legislation:* Same waste legislation at national and EC level must be followed (e.g. European Waste Catalogue (EWC) and 91/689/EEC on hazardous waste). • *Shredding plant:* Same shredding plants and techniques are normally used after that the rail vehicles are cut down to smaller pieces. This means that the same recovery processes for different material fractions are possible. • *Requirements:* Customer requirements in the rail industry are similar to the legislated requirements within the automotive industry, e.g. producer responsibility per project and targeted recycling rates.

To reach the reuse and recovery rates specified in the ELV directive the automotive industry has among other things investigated ways to recycle the glass. The glass is removed prior to shredding and the fraction from Stena in Huddinge is sent to Miljöteknologi Midt-Norge AS in Meråker, Norway. They use a technique to produce foamed glass that is used as a road base since the material is light and has stable and anti-freeze properties (Internet reference, 2003).

It costs a small amount per ton to recycle the glass and comparable solutions do not yet exist for glass from rail vehicles, at least not in Sweden.

2.5 Bombardier Transportation EoL Experiences

The Design for Environment department at Bombardier Transportation has worked several years to increase the knowledge about end-of-life activities and material recycling. The activities at end-of-life are studied so that the environmental impact at EoL can be minimised by design improvements of the vehicles. When customer request, a recycling description can be made that includes the materials and drawings of the vehicle, so that components containing hazardous materials and substances (hazardous waste) can be identified at EoL.

The following examples give knowledge of scrapping methods that give an important contribution to the EoL competence at the Design for Environment department.

Intercity passenger cars scrapped by SJ

The passenger cars that SJ puts out of use are built round 1960 and they are sent to O Hallquist Återvinning AB in Nykroppa, Värmland, Sweden. Since there is a need to keep the wagons in service as long as possible the life length has been extended with appropriate maintenance, overhaul and refurbishment. Especially the interior and the textiles need refurbishment after a couple of years.

Between 2002 and 2005 SJ will scrap 158 passenger cars (Nilsson, 2004). Before the wagons are sent to Nykroppa, SJ checks if components like thermometers, batteries, fire extinguishers and blankets can be reused.

In the scrapping activity first electrical and electronic equipment and environmental hazardous components are being removed e.g. the rectifier equipment that may contain PCB. Fluids, glass, porcelain, PVC-carpets, wood, plastic and insulation is being removed. If wheels and bogies can be reused by SJ they are sent back. Rest of the vehicle is being cut down to pieces and the metal content is being extracted and recycled.

About 90 % of the wagon is recycled, either as ferrous scrap, copper or brass that can be sent directly to recycling, or mixed scrap that goes to Stena Gotthard Återvinning and Fragmentering in Hallstahammar for separation in the shredding process. The main materials of these rail vehicles are ferrous metals and wood (Jonsson, 2001).

Test intercity trains scrapped by Bombardier

1 An intercity train produced round 1960 was used to test propulsion equipment in England. It was scrapped spring 2001, but all interior parts had been removed previously. The weight of the four cars was 160 tons and main material content was steel. It was scrapped by Stena Gotthard in Hallstahammar. The waste specification states that 7.4 tons were put to landfill. 295 kg capacitors and some other waste was sent for safe destruction. 200 liters of oil was recovered. Waste specification also states that weight of electric motors was 7 ton, 1.7 ton cables was removed, 0.8 ton aluminium and 3.2 ton transformers (R Larsson, 2001).

2 A Bombardier prototype and test ICN vehicle (6-car unit) was built 1997 and scrapped 2001 in Switzerland. After removal of the 26 ton components per car that could be reused in the series production (bogie, drives, batteries, air conditioner etc), the supplied weight per car was 18 ton. Of that 9 ton was the aluminium carbody. Disposal company was Thommen AG in Kaiseraugst. Disposal was made after legislation BUWAL (M Buergin, 2002).

Metro cars scrapped by SL

SL scraps the old metro cars (C2, C3, C4, C12 and C13) in Stockholm in the same rate as modernisation is made by buying in the new Stockholm metro cars C20 and C21, manufactured by Bombardier Transportation. About 600 metro cars will be scrapped 1998-2004. The metro car that was followed during the study visit was C13 1179. The series that have been scrapped (and the ones that will be scrapped) was built between 1949 and 1967 and were rebuilt round 1980.

The scrapping is organised by Tågia (Centralverkstan) that is a subsidiary company to SL and Tågia is also partly owned by Bombardier Transportation. Wheels, engines and obsolete parts are recovered to reduce later reparation costs on remaining fleet. Centralverkstan removes hazardous components like capacitors, fluorescent lamps, batteries, other electrical equipment and a heating radiator in the drivers cabin that still might contain a little bit of asbestos. All oil is tapped and the bogies are washed to minimise the pollution at the scrapping site (Å Eriksson, 2002).

The metro cars are then transported to Stena Bilfragmentering in Gladökvarn, Huddinge, which mainly scraps automobiles. At Stena Bilfragmentering the entire 25-ton metro car (except too thick pieces e.g. couplers) is cut down to pieces and shredded in a hammer mill. The cutting only takes 1-2 hours, but some more manhours are associated with the hand-operated cutting with blowpipe and sorting of materials. The metal fraction is recycled and other materials are put to landfill, including the glass that today is recycled by the automotive industry and the producer responsibility (N Habashian, 2002).

3 Conclusions

The conclusions are primarily based on the Swedish market situation.

In order to optimise the EoL activities regarding minimised environmental impact and costs, disassembly studies give important knowledge to designers how to design for disassembly and recycling.

The amount of disassembly prior to shredding of a rail vehicle varies and important parameters are: plant, tools, infrastructure, costs, beforehand knowledge about the vehicle with respect to composition and material content, waste legislation and network of receiver of a disassembled component.

So far the EoL treatment of rail vehicles in general has been driven by the metals and their positive value. To shred the major content of the vehicle to extract the metals is the most common way due to its cost efficiency. In the shredding process there are no principal differences in how materials from a rail vehicle vs. materials from an automobile and other waste are recovered. More severe restrictions in the waste handling, (e.g. from the landfill directive, hazardous waste classification) lead to that most market actors see that the costs related to waste handling are increasing at present. But in future also an increased house holding of resources is expected and it is expected that the interest to recycle and to use recycled materials will increase.

Customer requirements of recyclability rates for the rail industry are similar to the requirements that are legislated on the automotive industry in the End of Life Vehicle directive. This together with other waste legislation e.g. the prohibition to landfill combustible and organic waste, lead to that facilitation of recycling and recovery fractions and developments of the post-shredder treatment technologies are of same importance to the rail industry as for the automotive industry. It is important to increase the recycling and recovery rate of the shredder residues, especially the organic fraction.

Rail vehicles are many times recycled at the same plants as automobiles. Similar components as for the automotive industry need to be disassembled before a rail vehicle is shredded (e.g. batteries, fluids and components with mercury). But the parts do not look the same and the difference in size and number of vehicles produced between a rail vehicle and an automobile are important aspects. Furthermore, when times come to scrap a vehicle, recycling manuals are often lost. These facts open up many possibilities for a harmonized and partly common recycling system for rail and automotive industry. For example, a standardised system with symbols identifying hazardous substances would be beneficial.

Cost efficiency evaluations today lead to that the recycling industry believes that material separation after shredding processes will increase in future and this means that disassembling prior to shredding will not increase. However there is an aspect that point in opposite direction: A clean fraction of a specified quality of aluminium or stainless steel may generate a higher value than a fraction of mixed qualities (that often today is the result of the shredding process). An increased knowledge of the products together with a design towards easier disassembling increases this possibility.

There is no natural driving force in Scandinavia today to recycle materials such as glass, polymers and other organic materials, an extra cost is associated with the recycling activities. The demand to use recycled material in new production must increase for all industries to achieve the necessary logistic chains. The rail industry would have benefits if pre-disassembled parts e.g. glass and composites could follow the same recovery route as the material from the automotive industry, since larger volumes are associated with End of life treatment of automobiles.

Legal trends point in the direction that producers will probably take more responsibility for the EoL treatment of their products in future. The Swedish government evaluated the producer responsibility concept 2001 and found mainly positive effects on the environment and the national economy. For larger vehicles a legislated producer responsibility was not suggested, since there is a functioning market for second hand vehicles and spare parts. New regulations induced by the landfill directive and hazardous waste classification will also increase the demands on the EoL treatment and this together seemed sufficient for larger vehicles like trucks and rail vehicles (Internet reference, 2003). Another reason why producer responsibility is less appropriate for rail vehicles is that the considerable longer life length than automobiles leads to that a large fraction of the material content is often changed during life length in refurbishment activities. The recycling of the parts that are removed during the life length needs also to be considered. Today there is not a big waste problem with EoL rail vehicles since the control of the vehicles is good. The business is state-owned or run by big private operators and the end-of-life treatment is controlled by laws. The area needs continuous improvements though; both design improvements, scrapping methods improvements and material logistics improvements to reach a more sustainable situation.

4 Acronyms and abbreviations

DfE	Design for Environment
DfR	Design for Recycling
ECRIS	Environmental Car Recycling In Scandinavia (1994-1998)
ELV	End of Life Vehicle
EoL	End of Life
EPD	Environmental Product Declaration
Rail vehicles	Intercity trains, regional trains, metros, locomotives etc

5 References

Literature

Environmental Product Declaration, Regina, Bombardier Transportation, 2001

Environmental Product Declaration, Stockholm Metro Car, Adtranz (Bombardier Transportation), 1999

Environmental Product Declaration, DT 4.5 Underground Vehicle for the Hamburger HOCHBAHN AG, Alstom, 2002

Mannheim V (2001) Decision support for take-back and end-of-life treatment of Adtranz (Bombardier Transportations) rail vehicles, GEP Gesellschaft fur Entwicklungsberatung & Produktrecycling mbH

Hernborg, N (1998) ECRIS – a research project in environmental car recycling 1994-1998, Report no 98:17

Larsson Y (2001) Recycling of Materials in Rail Vehicles – in theory and practice, Master's thesis Luleå University of Technology/Bombardier Transportation, 3EST 7-866

Database

ENVIRA 2.1, a Bombardier Transportation developed Microsoft Access database for material and environmental related data per project

Personal contacts

Study visit at Tågia, centralverkstan and Stena fragmentering, Gladökvarn, Huddinge 2002-10-02.

- Åke Eriksson, Tågia
- Naznoush Habashian , Stena.

Study visit and information from Rolf Larsson, Stena Gotthard, Hallstahammar 2001-06-20

Information from Patrik Jonsson, O Hallquist Återvinning AB 2001-08-13 and newspaper article by Nilsson M (2004) Miljövänlig skrotning av gamla sittvagnar, SJ Nytt nr 4, 12 maj 2004

Information from Markus Buergin, Bombardier Transportation, Pratteln, Switzerland 2002-10-01.

Information on the Internet 2003-03-07

Glass recycling: http://www.oslo.sintef.no/smb/2000-04/10a.html

Producer responsibility investigation: http://miljo.regeringen.se/propositionermm/sou/pdf/sou2001_102samf.pdf

Alstom-Agimus disassembly study: http://www.agimus.de/dzplhbsum.html

Rev	Date	Description of revision	Prepared	Approved
0	2003 03 07	Issued	Ylva Larsson	Åsa Ander
1	2004 08 30	Change in text, mainly in section two	Ylva Larsson	Sara Paulsson

Appendix G

VOLVO

ER- 59934

Engineering Report

Date	Report Type				
2003-09-02	Test	Calc.	Design	AE	Misc.

Receiver (department, name, location)	Requisition/order no.	Project no.	Secrecy level
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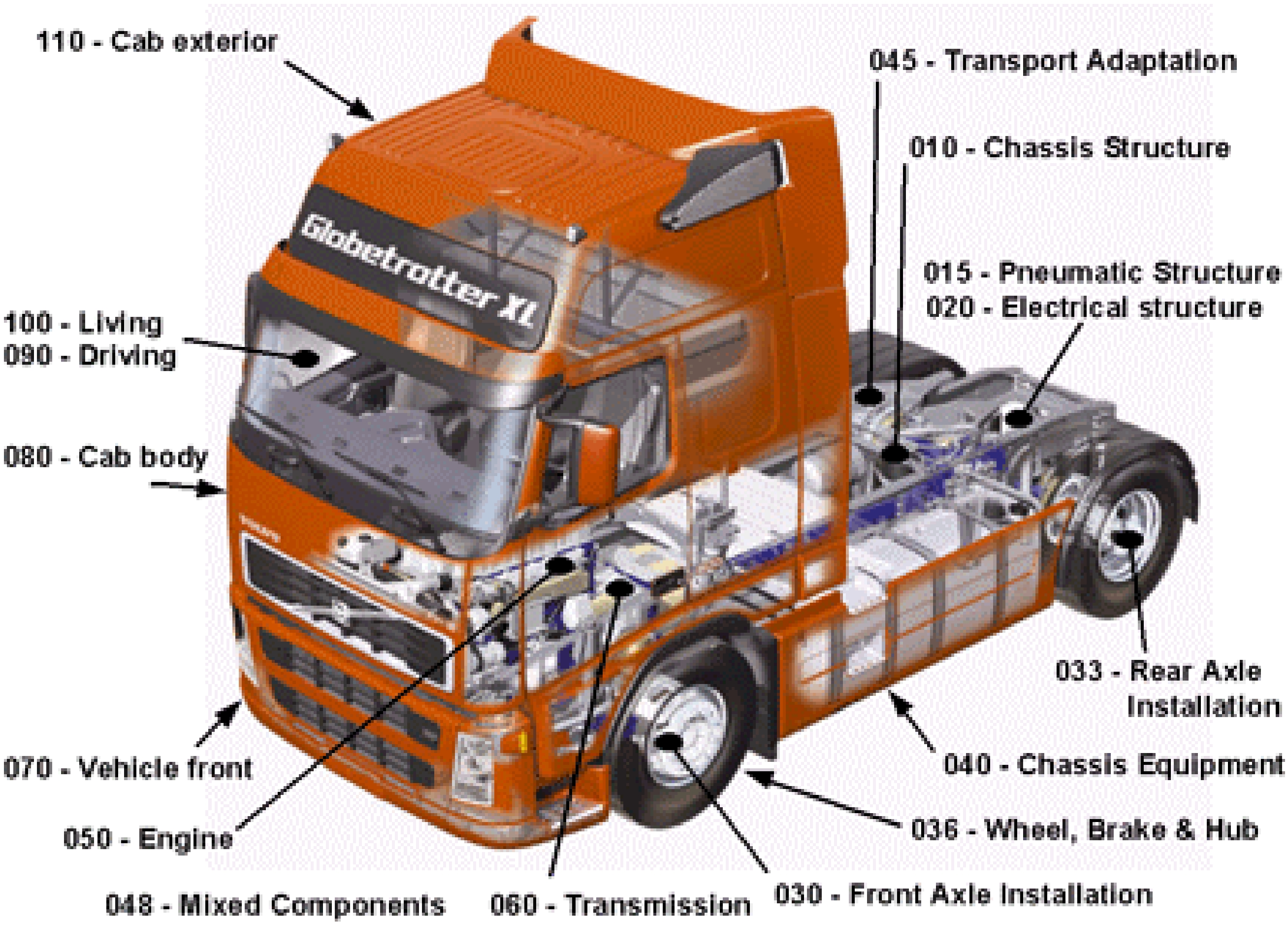
Approval date	Date carried out	No of Pages	No of Appendices
2003-09-11	2003-02-01– 2003-09-10	29	4

Advanced Engineering Area	Key Technology Area	Property Area
Complete vehicle	Product	Environmental and life cycle assessment.

End of life for trucks in Europe and material recycling



Abstract

It is forecasted that the regulation on producer responsibility applied to personal vehicle market may come into force on other Volvo products e.g. trucks, buses, boats and working machines. Volvo has the ambition to be proactive in the response to legislation.

The issue has been addressed by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material Systems) where a project called “Design for recycling” was initiated in cooperation with ABB, Akzo Nobel, Bombardier, SAAB, AB Volvo and Volvo Car Corporation in the end of 2002. The aim of the CPM project is to increase the knowledge of the manufacturing industry for the mechanisms that control how their discarded products are recycled. This knowledge can make it possible for the industry to develop more resource saving products and to get control of their costs related to producer responsibility.

This study is a part of that project. The purpose of this study is to have a basis for how the Volvo products may be Designed For Recycling and to contribute to the CPM survey of the recycling market in Europe, scenarios of future recycling markets and recycling systems, construction advice to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials and increase the recycling grade. The objective is to have knowledge on a general end of life treatment of trucks in Europe today and to identify trends for the future. The recycling possibility of a truck and recycling technologies for some plastics and elastomers as well as glass, will be identified.

The results of the study show that in Europe, the currently most common end of life for a truck is likely to be export to outside Europe. The trends in dismantling are that export of components increase, actors are becoming fewer and larger, illegal export increases and fewer parts are possible to reuse due to increased complications in dismantling. Regarding the recycling material in a truck it is likely that technologies for recovering materials after shredding, will be the most efficient option. Sorting of materials in the dismantling followed by aggregating materials, is perceived among dismantlers as well as recycling industry, to be less efficient. The rate for the recycleability of a truck depend on what parts that are dismantled. There is no such data today, but a model, based on an extensive component list, has been develop for a truck.

It is likely that an ELV directive on trucks is avoided and that the legislation for recycling of the materials in the components will instead be posed on to the consumer.

Sammanfattning

Det har förutsetts att idag gällande lagstiftning för producentansvar för personbilar kommer att föras vidare till andra Volvo produkter såsom lastbilar, bussar, båtar och arbetsmaskiner. Volvo har ambitionen att vara steget före i förhållande till lagstiftning.

Frågan har identifierats av CPM (Chalmers kompetenscentrum i produktrelaterad miljöanalys) där man har initierat ett projekt som kallas “Konstruktion för återvinning” I samarbete med ABB, Akzo Nobel, Bombardier, SAAB, AB Volvo och Volvo Car Corporation, i slutet av 2002. Syftet med CPMprojektet är att öka kunskapen hos tillverkningsindustrin om de mekanismer som styr hur deras slutanvända produkter återvinns. Denna kunskap kan möjliggöra för industrin att utveckla mer resursbesparande produkter och att få kontroll over kostnader som är relaterade till producentansvar.

Denna studie är en del av det projektet. Syftet med denna studie är att ha ett underlag för hur Volvoprodukter kan utformas för återvinning och att bidra till CPM undersökningen av återvinningsmarknaden i Europa, Scenarier av framtida återvinningsmarknader och återvinningssystem, konstruktionsråd för att underlätta återvinning av produkter, bidra till kostnade effektiva återvinningsprocesses, öka värdet av återvunnet material och att öka återvinningsandelen. Målet är att ha kunskap om en allmän sluthantering av lastbilar i Europa idag och att identifiera trender för framtiden. Återvinningsmöjligheterna för en lastbil och återvinningsteknologier för några plaster, gummi och glas, identifieras.

Resultatet av studien visar att i Europa, så är den nuvarande mest vanliga sluthanteringen av en lastbil, att den exporteras utanför Europa. Trenden i demontering är att export av komponenter ökar, aktörerna blir färre och större, illegal export ökar och färre delar är möjliga att återanvända beroende på ökande problem i demontering. När det gäller återvinning av material i en lastbil så är det troligt att teknologier för återvinning av material efter fragmentering, är det mest effektiva alternativet. Att sortera material vid demontering följt av uppsamling, upplevs bland både demonterare och återvinningsindustrin, att vara mindre effektivt. Återvinningsgraden av en lastbil beror av vilka delar som demonteras. Idag finns ingen statistik över detta sammanställt, men en modell, baserad på en utförlig komponent lista, har tagits fram för en lastbil.

Det är troligt att ett ELV direktiv på lastbilar kan undvikas och att lagstiftning för återvinning av material i komponenter, istället läggs på konsumenten.

Acronyms and abbreviations

ASR – Automotive Shredder Residues
CPM – Chalmers Competence Centre in Environmental Assessment of Product and Material Systems
ELV – End of Life Vehicle
HW – Hazardous waste
MSW – Municipal Solid Waste
PST – Post-Shredder Treatment
Recoverability rate - Percentage by mass of a new vehicle that can potentially be recovered, reused or both.
Recovery Reprocessing - in a production process, of the waste materials for the original purpose or for other purposes, and the processing as means of generating energy.
SR – Shredder Residues
SFS 1997:788 “Svensk FörfattningsSamling”, Producer responsibilitiy for vehicles

Contents

1. Introduction

*Reducing the environmental impact of the transport sector to a long-term sustainable level, is one of the greatest challenges facing the automotive and transportation industry today. Volvo has a long tradition of working with environmental issues, and environment is one of our Core Values. Our environmental activities take account of the environmental impact of the product at every stage of its lifecycle. [*http://www9.volvo.com/truck/ 030430]

Background

In the European Union approximately 5.5 million cars are scrapped each year. The EU Directive 2000/53/EG has set forward requirements on how much of this scrap that has to be reused or recycled, how much that can be incinerated for energy recovery, and the maximum amount that can be put to landfill by the years 2006 and 2015.

It is forecasted that the regulation applied to personal vehicle market may come into force on other Volvo products e.g. trucks, buses, boats and working machines. In order be proactive in the response to legislation to come, Volvo need to be prepared.

The issue has been addressed by CPM (Chalmers Competence Centre in Environmental Assessment of Product and Material Systems) where a project called “Design for recycling” was initiated in cooperation with ABB, Akzo Nobel, Bombardier, SAAB, AB Volvo and Volvo Car Corporation in the end of 2002. This study is a part of that project.

The aim of the CPM project is to increase the knowledge of the manufacturing industry for the mechanisms that control how their discarded products are recycled. This knowledge can make it possible for the industry to develop more resource saving products and to get control of their costs related to producer responsibility.

Purpose

The purpose of this study is to have a basis for how the Volvo products may be Designed For Recycling and to contribute to the CPM survey of the recycling market in Europe, scenarios of future recycling markets and recycling systems, construction advice to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials and increase the recycling grade.

Objectives

The objective is to have knowledge on a general end of life treatment of trucks in Europe today and to identify trends for the future. The recycling possibility of a truck and recycling technologies for some plastics and elastomers as well as glass, will be identified.

Scope

The study focus on the end of life of trucks in Europe and what the trends are regarding legislation on producer responsibility, development of recycling technologies for plastics and elastomers and how to enhance recycling of the Volvo Truck.

To get the prices of the waste treatment options right is perceived as being a bottleneck to recycling. Thus it is given extra focus.

Cooperation and benchmarking with the CPM members in the project allow for a broader and deeper understanding.

Principles and guidelines for the design and construction are to be formulated in a later stage 2004.

2. Methodology

Information has been searched for on the internet and in literature but mostly through personal contacts.

The end of life of trucks in Sweden and Europe is outlined as far as possible. Dismantlers in Sweden are contacted in order to identify bottlenecks and trends. The dismantling and material recycling of a truck is also studied via the current Volvo Design for environment Guidelines.

To identify future trends branch organisations for automobile and recycling industry have been contacted regarding forecasted legislation on the ELV and regarding development of recycling technologies for PUR. The other project members investigate recycling technologies for other materials. A common report will be available.

A bottleneck to recycling is that, the cost of waste treatment and price for the recycled material, is not known. Recycling options for critical materials have been analysed by each partner in the CPM project. The compilation of those options is a step to fix the price in order to initiate recycling. How the value of materials for recycling may be estimated is studied and discussed.

3. Results

Current end of life for trucks

Sweden

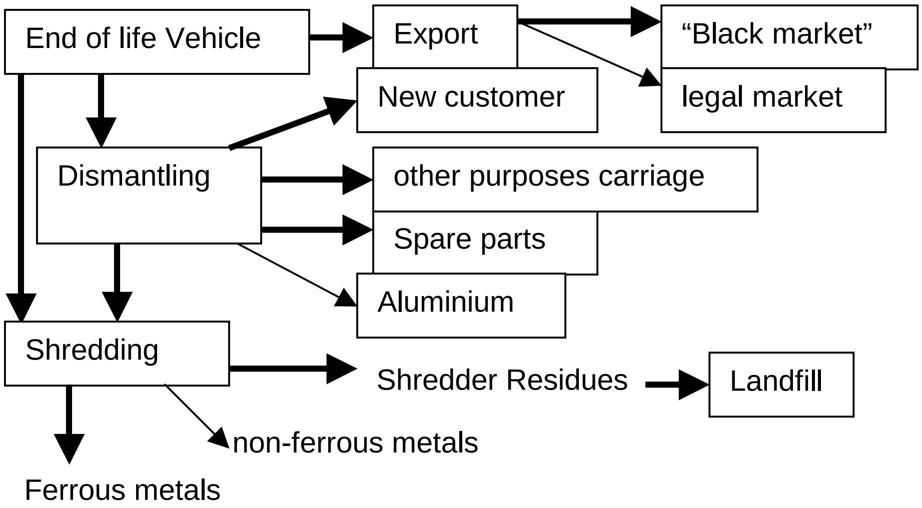


Figure 1: End of life scenario.

In Sweden, approximately 13 % (4801) of new registered trucks (37184) are being registered off road each year [Barsoum K.]. That is 48% go to export, 26 % are taken care off by an authorised dismantler, 15 % are dismantled or used by other means, 3 % are not in traffic and 8% are reregistered to other vehicle or have not been noticed for two years.

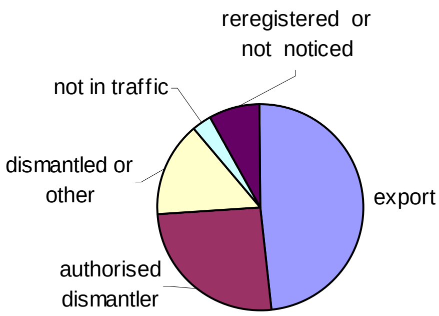


Figure 2: Trucks in Sweden registered off road.

Looking back 30 years, the trend is that the share of trucks going to export increase and the amount of “end of life” trucks had a peak in the late 80´s and beginning of 90´s [Hultberg T. Bil Sweden, 2002]. There are approximately 7 major dismantlers that together have a throughput of approximately 1200 vehicles per year [Sundin L.]. Many of the vehicles passing through the dismantler are possible to sell directly further to a new customer (approximately 30% or 360 vehicles per year). It is assumed that a very small fraction goes directly to shredding. A large fraction of the end of life trucks is black market export [Sundin L.]. Assuming that all vehicles that are not registered to export or dismantling are sold on the black market, would imply an optimum off 1640 trucks.

Via telephone interview with the major Swedish Dismantlers it was found that the dismantler keeps the truck as storage of spare parts until it is no longer worth saving. Demanded spare parts are dismantled as well as precious materials such as aluminium. The chasses are sometimes sold as a carriage. When it is no longer worth keeping, it is sent to shredding at Stena Gotthard Fragmentering AB (4 facilities), where it is cut to smaller peaces and sent to material recycling at Stena Gotthard Återvinning AB (54 facilities) [Domini P]. It has not been possible to identify how many trucks that come in to shredding at Stena each year. Stena will look further into this during autumn 2003 [Ödman B.].

Europe

In Europe there is no registration when trucks are taken off road. Therefore it is not possible to know very much about the end of life. In order to gain some of the end of life for a truck in Europe and what the trends are, a few initiated organisations was contacted.

Netherlands

According to prior project manager for Recycling at Auto recycling Netherlands (ARN), there is no statistical information regarding the end of life of trucks in Netherlands. Most likely is that they go on export [von Celdhuizen Mark]. According to his successor Rieks Jansen at the Auto Recycling Nederland there is not much done fore recycling on ELV Trucks in the Netherlands. Most of the ELV trucks are being exported. Some truck dealerships do have their own dismantling halls, but they only dismantle trucks that have been in accidents. They dismantle spare parts to resell those parts, and the remaining steel will go to a shredder site, and for waste materials the normal waste disposal routes. Before the truck will be shredded it will be drained for oil and other fluids. This will only be a few percent of the total of ELV trucks. [Jansen R.]

STIBA is the Dutch association of certified car, motorcycle, truck and related dismantlers. STIBA has a special group of truck dismantlers [Laar Franklin van de].

France

One large dismantler in France is Valerco located in Lyon (dismantle only passenger cars). In France, there is a system of certification of dismantlers.

According to Christiane Otdjian at Environmental Affairs, RENAULT V.I, export to Africa is probably the most common end of life for trucks in France. There are two categories of economic actors; dismantlers who disassembly manually the cars and sell components and crushers who destroy the cars and sort the different materials by automatic ways.

Renault is responsible (at the economic level) for the end of life treatment of the vehicle put on the market, and chose between dismantlers and crushers. A main actor of recycling that Renault is in contact with is a company called CFF Recycling (http://www.cff.fr). CFF Recycling runs local community waste collection centres. In addition, some fifty metal collection centres have been set up as receptions for all small quantities of metal waste.

Material content of trucks and material recyclability

The model for recycling possibility of a truck prepared and recycling technologies for some materials is identified in cooperation with the other parties of the CPM project (see list of participants). It was decided that Volvo AB, Volvo Cars and Bombardier together focus on PUR, composite, glass and rubber. This report focuses on PUR.

The material in a truck today has been listed in an environmental LCA study that was prepared as a basis for the EPD (Environmental Product Declaration) ref [http://www9.volvo.com/truck/ customer offers] on the Volvo Truck FH12 and FM12 (P 2285). This EPD describes the environmental impact of the European-built Volvo FH and FM trucks from a life-cycle perspective – from cradle to grave. The results are available both as web brochures and as online calculated data.

	Environmental Product Declaration Volvo FH 12 and FM12, Euro 3	
Material	**Kg**	**From recycled material (%)**
Iron		
Wrought, tempered	1196	50%
Cast	1478	97%
Steel		
Rod	198	
Hot-rolled	1645	
Cold-rolled	925	
Other metals		
Aluminium	201	90%
Lead (battery)	95	50%
Copper	14	40%
Brass, bronze	9	86%
Stainless steel	15	80%
Plastics		
Thermoplastics	339	
Reinforced thermoplastics	74	
Thermosetting plastics	6	
Other materials		
* Rubber	459	
Glass	60	
Textile, other fibres	57	
Paint	13	
Brake pads	22	
Oil, grease	62	
Electronics	56	
Sulphuric acid (battery)	36	
Bitumen	6	
Wood	11	
Cooling agent (R134a)	1	
Glycol	17	
Ethanol	4	
Total	7000	33%

Table 1: List of materials in a truck [Klintbom P. EPD Volvo Trucks 2001]

* The trucks are delivered with low content PAH type of tyre treads. The rubber is mainly from the tyres that also include steel wire thread.

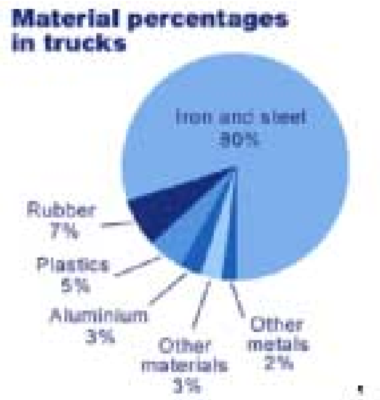


Figure 3 Material composition of a truck [http://www9.volvo.com/truck/]

The rate of the materials that are possible to recycle may be calculated via the iso standard for road vehicles recycling ability and recoverability [International Organisation for Standardisation]. This standard aims to describe a general calculation method of the recycling ability and recoverability rates based on four main stages inspired by the treatment of end of life road vehicles. The rates depend on design and material properties of the new vehicles and the consideration of proven technologies for recycling of material.

The following acronyms are used in the calculation:

mass of materials taken into account at the pre-treatment step	mP
mass of materials taken into account at the dismantling step	mD
mass of metals taken into account at the metal separation step	mM
mass of energy recoverable materials	mTe
mass of vehicle	mV

Table 2: Acronyms in calculation of recycling ability.

An excel sheet [appendix 2] created by Herman Lindström at Volvo Wheel Loaders, was used as a model for the calculation of the Volvo FH12 [appendix 1]. Due to that it is not yet sufficiently identified what components that are dismantled, the calculation include dismantling of all components, and maximum material specific recycling possibility. Therefore the rate is almost hundred percent for the potential.

- Recyclability rate (Rcyc) = 94 %.
- Recoverability rate R(cov) = 100 %.

During the calculations it has been difficult with the division in fractions for pre-treatment, dismantling, metal separation and energy recoverable materials. The reason is that their weight is included in all the moduls, which in turn are more perfectly described, transparent and easy to calculate. Thus to facilitate the calculation of recycle ability, the material content in each modul should be calculated. The materials in the modules that are dismantled or may be dismantled, substitute the recycleable materials.

PUR Polyurethane

Polyurethane (PUR) is produced from the liquid basic materials polyhydric and isocyanate. After mixing the two components (under certain mixture ratios), a spontaneous increase in hardness or cross linking into the polymer form of PUR occurs. By adding various reagents, a variety of polyurethane foams with the most different qualities can be produced.

PUR has a risk because it contains iso cyanate that may be released in processing and gases that may form in fire. Extruded PUR can be cut and rebounded to a new part. In incineration poisonous gases may form. PUR has a low energy value. [Lindkvist L.]

Energy recovery is commonly accepted in Europe. Landfill of PUR is expensive. Mobius Technologies has developed a technology where PUR residues are moulded to powder and replace 10 per cent of new polyol. Cannon has developed equipment that mixes the powder with polyol and isocyanate directly in the injector head [Vik B. 2003]. During the regrind method, where finely ground powdered PUR is added again to the polyhydric component, the recyclate can only be added at a ratio of approx. 10% due to the resulting ductile nascent viscosity.

Chemical recovery is developed via Løgstør Rør in Denmark as well as H&S Anlagetechnik. H&S cooperate with Regra Ecosystems in Pirmasens in Germany [Vik B. 2003]. Chemical recycling is the only method that offers the possibility to produce high-quality polyurethane products from 100% recycled polyhydrics. Glycolysis has since long been known as a method for chemical recycling of high-resistance foams and integral skin foams. For the raw material reutilisation process of semi-high-resistance and soft foams made of PUR, regra ecosystems has developed three new methods (partial glycolysis, polyolysis, acidolysis) in cooperation with the FH Aalen and has also used them for the first time industrially. Regra Ecosystems has managed to implement all recycling methods industrially in a recycling plant developed by regra ecosystems mentioned above and thus industrially utilisable now. Another ecological advantage of chemical reutilisation of residual PUR-substances in contrast to energy recovery (combustion) is that it does not trigger any environmentally damaging release of CO_2. The method causes neither exhaust fumes nor solid or liquid waste based on the method. The formation of aromatic amines is avoided by the specifics handling of the chemical process. [Regra Ecosystems]

According to Mr Kroesen at Elastogran it is not economically viable to recycle polymeric materials from trucks into new material. It would be far too insecure to speculate in market prises. Mr Kroesen says that mechanical recycling of Polyurethane is possible and is practiced, however the commercial viability depends very much on narrow markets for the recycled materials. For durable goods it would be extremely speculative and risky to relay on specific recycle markets. Efforts therefore go into addressing the shredder residue. Elastogran certainly well come also selective disassembly with mechanical recycling, provided the case is commercially or at least environmentally viable without subsidies.

Elastogran is supporting an integrated Waste Management approach, focused on the organic shredder residue. They are cooperating with BASF and DOW to develop a method for organic Shredder residue in general that under high pressure can produce methanol. An optimised process would require 200 000 tons per year, which is an investment that demand for a large industry to carry out. [Kroesen KW]

Rubber

The tires from a truck are being retreated (at AGI däck in Sweden) 1-4 times (buses 3-4 and working machines 1-2 times) before they are sent to other means of recycling (Ragnsells in Sweden).

Retreated	5 %
Export of complete + fragmented tires	5%+7 %
Reuse	2 %
Blasting carpet	4%
Material recycling	31 %
material substitution	25 %
Energy recovery heating plant + concrete industry)	13 % + 11 %
Landfill	0-1 %

Table 3: Tires end of life in general 2001 [Svensk Däckåtervinning website].

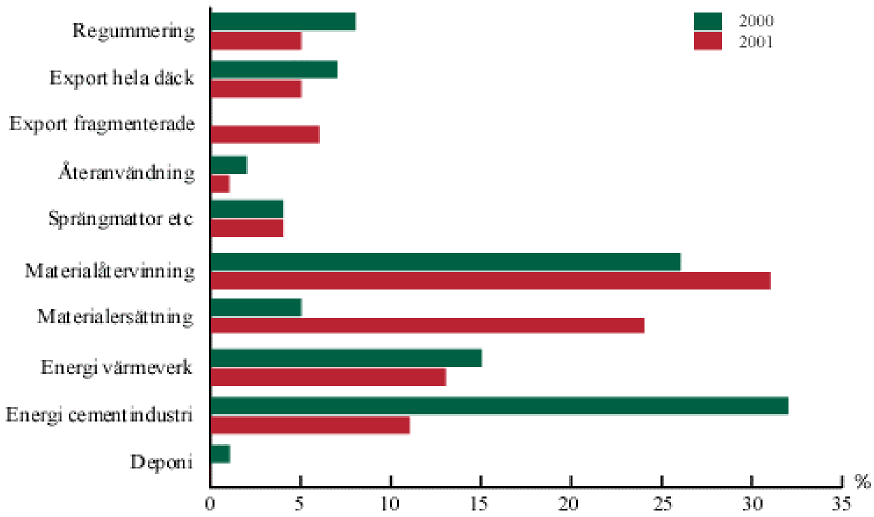


Figure 4: Diagram representing the composition of the end of life for used tires (all kind of tires) [Svensk Däckåtervinning website].

The rubber that is turned of is sold to other industry (Interwheel in Sweden) that either use it for energy recovery or sell it to material recycling [Lindström B.] Material recycling may be as whole tires in road banks, noise reduction, blasting carpets and collision protection. As chip it may be used in road paving, plates, “feet” to traffic signs and insulation material.

When it comes to recycling of rubber, the vulcanisation process makes it impossible to melt or reshape the material. Energy recovery is attractive due to the high energy to mass ratio, but the production of rubber requires much more energy than may be recovered. A method for material recycling is sulphur utilising micro organisms as described by Katarina Bredberg [2003].

Composite materials

In the latest Volvo DFR guidelines is says that: “Thermoplastics can be recycled to a certain extent, but energy recovery is complicated by reinforcement” [Lindkvist L.].

Composite materials or reinforced thermoplastics, have considerable potential for improving the performance of transport structures by reducing weight, providing good corrosion resistance, and enabling cost-effective processing. However, recent European Union legislation directives and consumer demands have put pressure upon the composites industry to develop recycling technologies for composite products at end-of-life. Composite materials cannot be easily recycled in the same way as un-reinforced thermoplastics. Instead it is necessary to develop dedicated recycling technologies. Several techniques have been studied in detail over the last 10 years. [Skrifvars M.]

Directive 99/31/EC on landfill of waste has led to that if composite containing plastics/resins fall under “organic matter” (which it does in all countries except for UK) landfill of fibre reinforced plastics (FRP) will soon be forbidden [Larsson Ylva]. It was decided that Ylva Larsson from Bombardier (see list of participants) identify the current trends with regards to technologies for recycling of composite.

Glass

In the latest Volvo DFR guidelines is says that: “Glass can be recycled, but should not be mixed with electric wires etc. “ [Lindkvist L.].

It was decided that Caroline Sjöberg (see list of participants) preparing the Volvo Cars part of the CPM project identify the current trends with regards to technologies for recycling of glass.

General principles and guidelines how to enhance recycling.

There are generally two strategies to recycling, either increased dismantling and reuse of components while sending a minor fraction to material recycling, or, shredding followed by increased shredder residue treatment. In order to give guidelines on how to enhance the recycling, potential obstacles to dismantling and material recycling is identified.

Dismantling

Requirements by the main actors in Sweden have been identified via telephone interviews.

Perceived tendencies among the dismantlers in Sweden are that:

The share of illegal market increases due to unfair concurrence.

Steel parts corrode faster.

Parts that are infused in plastics increase.

Parts are composed by many materials that are difficult to take apart.

Turning to large scale dismantling and thus increasing distance to customer.

The average dismantler is older thus implying a shift in generation.

Export to Eastern Europe increase.

More of the cabin is reused, which is positive.

Spare parts go to export.

Exterior parts are sometimes problematic due to difficulties in cleaning.

Suggestion on general principles and guidelines that apply to construction of trucks and also to the other Volvo products, have been formulated by Ingemar Dryséus Volvo Truck Corporation in the brief let called LCA-Design Guidelines [20100-99-128]. Guidelines will be further developed in the following report 2004. Means of facilitating dismantling have been suggested from the dismantlers:

Take action to prevent illegal market.

Reduce corrosion on critical parts such as labels and nuts.

Labelling that is functioning properly (e.g. do not fall off due to corrosion).

Avoid mixing of material such as casting aluminium and steel.

Dismantling manual as a software.

Spare parts catalogue.

A joint database system facilitate that the dismantler may identify what article that is requested and that a price may be estimated. (e.g. similar to that provided by Scania for 800 euro per year which has 10 users.)

Parameters that need to be addressed when estimating the cost of dismantling, have been suggested by Verein Deutscher Ingenieure [2002]:

Visual perceptibility (e.g.batteries, identified plastic parts)

Accessibility (e.g.direct access)

Detachability (e.g.nondestructive,destructive)

Multifarious connections (e.g.screwed,bonded, riveted)

Dismantling and breakdown time

[Verein Deutscher Ingenieure]

Material recycling

The rate of recycling will depend on the perceived demand for the reuse of components and recycling of materials as well as the cost and technical possibility to recycle. Thus, if recycling is worthwhile depend on the possibility for actors to rely on a stable demand and known costs for established methods for recycling. Getting the prices of the different waste treatment options right is addressed as a key strategy by the European Commission to promote recycling [Communication from The Commission]. Parameters that need to be addressed when estimating the cost of recycling, have been suggested by Verein Deutscher Ingenieure [2002]:

Materials

Ability to be identified (e.g.materials marked)

Recyclability of materials

Recycling compatibility in material compounds

Environmentally critical contents, which have to be removed specifically and eliminated separately (e.g.mercury switches)

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

Availability of economically optimised recycling processes for specific target fractions (e.g.efficient preparation of ABS housings)

[Verein Deutscher Ingenieure]

Future trends

Legislation

According to Dr Philipps at Integrated Environmental Policy at ACEA (European Automobile Manufacturers Association), it is not likely that an ELV directive will come into force. "… in a description of the strategy of the Commission on waste for the next years. I cannot see any indication from this document that a End-of-Life Truck Directive will be proposed in the next future." Instead the European commission will focus the recycling strategy on the consumer behaviour to push for recycling with taxes on landfill and encourage recovery. [Phillipps H.M.]

In Europe in general, strategy regarding waste streams in society is not clear, depending on the lack of statistical data to analyse trends. It is clear however that the amount of waste generated throughout the Community has increased significantly over the last decades. Strategic options to promote recycling include so far:

- The development of material based recycling targets in articulation with end-of-life products based targets;

- Getting the prices of the different waste treatment options right by using economic instruments, which could include tradable certificates, the co-ordination of national landfill taxes, promoting pay-as-you-throw schemes and making producers responsible for recycling.

- Ensuring recycling is both easy and clean. In some cases, implementation of EU waste law may have led to unnecessary burdens on the recycling industry. Such problems need to be identified and solved. Additionally, common approaches for recycling could ensure that recycling businesses apply the best available technology.

Material composition of truck

Based on discussions with Design Director [Orell R.] at Volvo Trucks, the trends in material composition of trucks is forecasted. The trend in development of trucks and buses is a shape that is more aerodynamic thus implying panels on the sides and beneath. Special surface treatment could also be an issue. Emission after treatment and electronic equipment will increase and fuel may change. Lightweight will be important as may sound insulation and requirements on safety. When making all those changes, it should be considered and taken into account that the design and construction of components is such that materials that need to be recycled will be so. Components that are costly to put on landfill need to be avoided if they cannot be recycled. However, materials that are not a scarce resource and do not have secondary value, would not have to be recycled.

The development of materials is suggested to follow the development of personal vehicles. Forecasted changes in the composition of materials are:

- Rubber to be reduced in favour of plastics.
- Sandwich material for noise insulation will increase (e.g. sheet iron and plastic combination).
- Electronics will increase, thus copper will increase.
- Plastics increase by 5 % annually in the personal vehicles.

General trend is lightweight as plastics composites, aluminium, magnesium and thin sheet iron.

4. Conclusions and recommendations

In Europe, the currently most common end of life for a truck is likely to be export to outside Europe. Due to that today there are no legal requirements on recycling trucks, there is no incentive other than market demand to dismantling. There is also lack of statistical data, which complicate the mapping of the end of life for trucks. The trends in dismantling are that export of components increase, actors are becoming fewer and larger, illegal export increases and fewer parts are possible to reuse due to increased complications in dismantling.

Regarding the recycling material in a truck it is likely that technologies for recovering materials after shredding, will be the most efficient option. Sorting of materials in the dismantling followed by aggregating materials, is perceived among dismantlers as well as recycling industry, to be less efficient. The possible recycling rate of a truck has not been sufficiently identified due to lack of statistical data on dismantling. However, there is sufficient basis of knowledge on the composition of a truck, to facilitate further calculations.

It is likely that an ELV directive on trucks is avoided and that the responsibility of recycling the materials in the components will instead be individually on the consumer. It may imply that the consumer will require that the truck be accepted at a certified recycling facility. The requirements of the certified recycling facility will be posed to the producer of the truck. Thus if the truck may easily be dismantled and/or the materials are recycled at sufficient revenue, it should imply a more satisfied customer.

5. References

Literature

1. Andersson/Wicksell, Kommentarer till LCA - Design Guidelines, LM 59712 Volvo Teknisk Utveckling AB, 1997

2. Bredberg Katarina, Suphur-Utilising Microorganisms in Biotechnological Applications-Rubber Recycling and Vanadium Reduction, Department of Biotechnology, Lund University. 2003

3. Berglund, Livscykelanalys - miljöhänsyn vid konstruktionsarbete, Reg. No 26644-5204, Volvo Lastvagnar AB, 1992

4. COMMUNICATION FROM THE COMMISSION, Towards a thematic strategy on the prevention and recycling of waste, COM(2003) 301 final, COMMISSION OF THE EUROPEAN COMMUNITIES, Brussels, 27.5.2003,

5. Domini P., handbook för konstruktörer, Stena Gotthard Återvinning AB.

6. Dryséus Ingemar, LCA-Design Guidelines 20100-99-128, Volvo Truck Corporation, VLH 6A, 990312

7. Hultberg Tommy, Avregistrerade lastbilar med totalvikt över 3,5 ton efter fabrikat, totalvikt, årsmodell och avregistrerings orsak, Bil Sweden, 2002.

8. INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Road vehicles — Recyclability and recoverability —Calculation method. DRAFT INTERNATIONAL STANDARD ISO/DIS 22628, ISO/TC 22 Secretariat: AFNOR, Voting terminates on 2001-12-19,

9. Klintbom P., Volvo Truck Corporation, Environmental Product Declaration –Volvo FH12 and FM12, www.volvo.com, Gothenburg, Sweden, 2001.

10. Larsson Ylva, 020515 Summary composite recycling sem, CoC Design for Environment, IFP SICOMP, May 14-15, 2002, Mölndal, Sweden

11. Lindkvist L., Environmental guidelines for product development, Volvo Truck Corporation.

12. Peters M.T.H., Guidelines for environmentally conscious design, drawing no 30813133, Volvo Car Corporation, 1994

13. Pickering Steve, 020515 SICOMP summary pdf, WORKSHOP May 15, 2002: OVERCOMING THE BARRIERS FOR RECYCLING OF COMPOSITES, University of Nottingham May 17, 2002

14. Sjöberg C, Post-Shredder Treatment Technologies 6700-03-04, Volvo Technology Corporation, Gothenburg, Sweden, 03-01-08.

15. Verein Deutscher Ingenieure, VDI 2243 Recycling-oriented product development, ICS 03.100.40;21.020, July 2002

16. Vik B.,Utech-Miljön på tur för PUR, PlastForum Nr 5 2003.

17. Westerlund A., Environmental guidelines for engineers, Volvo Car Corporation.

Personal contacts

1. Barsoum Karim, Vägverket, karim.barsoum@vv.se, +46 (019) 192656

2. Celdhuizen Mark von, proj manager for recycling, ARN, Auto recycling Netherlands, 0031 (0)20 6613181, info@ARN.NL

3. Ekman Rolf, Ekmans i Hedkärra AB, http://www.ekman.biz/

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5. Hans-Martin LENT-PHILIPPS, INTEGRATED Environmental Policy, European Automobile Manufacturers Association, Rue du Noyer 211, B-1000 BRUSSELS - Phone +32-2-7387341, Fax +32 2 7387310,email: LPM@acea.be, Concept, Design & Development.

6. Hultberg Tommy, Bil Sweden, Tommy.Hultberg@bilsweden.se, +46 (08) 7016333

7. Jansen Rieks, Auto Recycling Nederland, Research Center Amstelveen, Grutterij 2, 1185 ZV Amstelveen, t 0031(0)20-5035080, f 0031(0)20-5035081, e arnresearchcenter@zonnet.nl, rieks.jansen@arn.nl, i www.arn.nl

8. Kroesen Karl-Wilhelm, product safety and ecology -Elastogran,karl-wilhelm.kroesen@elastogran.de

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10. Lindström Björn, AGI DÄCK AB, BOX 34, SE-334 21, ANDERSTORP TEL.+46 (0)371 192 00 FAX +46 (0)371 179 40

11. Lindström Herman, Volvo Wheel Loaders AB, UTL-6, Eskilstuna, tel: 016-151360

12. Nordström Jan, Nordströms Bildemontering AB, Nordstromsbildem.com Nordstroms.jan@telia.com, Gälltoftavägen 117, Box 14051, 291 14 Rinkaby
Telefon: 044-572 00 Fax: 044-573 70

13. Otdjian Christiane, Environmental Affairs, RENAULT V.I.VENISSIEUX, France, +33 472 968527,

14. Willkrans Rolf, AB Volvo.

15. Skrifvars Mikael, Group manager Materials, Ph.D. Polymer Chemistry, SICOMP AB, POBox 271, SE-94126 Piteå, Sweden, phone: +46 911 74415, fax: +46 911 74499, mobile: +46 70 234 8562, http://www.sicomp.se

16. Åhman Lars, 070 5575099 Sveriges Bilskrotares Riksförbund.

17. Ödman Bo, Stena Fragmentering, Bo.Odman@stenametall.se, 035-223316.

Website

1. AGI DÄCK AB http://www.agidack.se

2. Arvamet AB, www.arvamet.se

3. Automotive Recyclers Association, www.autorecyc.org

4. Bayer http://www.bayer.com
5. Bil Sweden, http://www.bilsweden.se/webdoc.asp
6. Boliden, www.boliden.se
7. Bureau of International Recycling, www.bir.org
8. CPM http://www.cpm.chalmers.se
9. ECO VHU http://www.eco-vhu.com/html/page6vhu.htm
10. Ekmans http://www.ekman.biz/länkar.htm
11. Elastogran http://www.elastogran.de/
12. European Group of Automotive Recycling Associations, www.egaranet.org
13. Global Recycling Network, www.grn.com
14. Huntsman Polyurethanes http://www.huntsman.com/pu/
15. H&S Chemical Co. Inc. http://www.hschem.com
16. Interwheel AB http://www.interwheel.se
17. Kuusakoski, www.kuusakoski.com
18. Mobius http://www.mobius.com
19. Plastics in ELV, www.plastics-in-elv.org
20. Regra Ecosystems http://www.regra.de/presse/regra_ecosystems_engl.doc
21. Stena Fragmentering AB, www.stenametall.com
22. STIBA, Dutch Association representing certified car, motorcycle, truck and related vehicle dismantlers. http://www.stiba.nl/
23. Svensk Däckåtervinning http://www.svdab.se/startsida.cfm
24. Sveriges Bilskrotares Riksförbund, www.sbrservice.se
25. Volvo http://www.volvotrucks.volvo.se/frameset.asp
26. Volvo http://www9.volvo.com/truck/
27. Återvinningsindustrierna http://www.recycling.se

Appendices

appendix 1: Calculation model of recycling ability of Volvo FH12 and FM12 [Wendin M.].

	Brandname	Volvo		Machine mass (ma) (kg)				
	Model	FH 12 and FM12		7000				
	Material comp. (kg)	Metals	Polymers (excl elastomers)	Elastomers	Glass	Fluids	MONM	Others
		Mass (kg)						
		5726	420	459	60	84	153	49
			Mass (kg)					
	Fluids	mp1	84					
	Battery	mp2	128					
	Oil filters	mp3	2,4					
	Tyres	mp4	485					
	Cathalytic converter	mp5	84					
Pretreatment (mp)		mp6						
		mp7						
	Total mass (mp) (kg)		783					
	Partnumber	Name		(kg)	Metal content (%)			
	Parts in all modules	electrical comp. and cable		258	41%			105
	Module 010	Chassis Structure		615	86%	calculated		530
	Module 015	Pneumatic structure		60	81%	calculated		48
	Module 020	electrical structure		0,3	99%	guess		0,3
	Module 030	Front axle installation		537	100%	calculated		536
	Module 033	rear axle installation		713	100%	calculated		712
	Module 036	Wheel, brake and hub.		862	63%	calculated		545
	Module 040	Chassis equipment		389	70%	calculated		272
	Module 045	Transport adaptation		14	100%	calculated		14
	Module 048	Mixed components		193	38%	calculated		73
	Module 050	Engine		1188	96%	calculated		1146
	Module 060	Transmission		345	97%	calculated		334
	Module 070	Vehicle front		109	86%	calculated		94
Dismantling (mD)	Module 080	Cab body		554	98%	calculated		543
	Module 090	Driving		190	79%	calculated		151
	Module 100	Living		236	93%	calculated		219
	Module 110	Cab exterior		202	99%	calculated		200
	Total mass (mD) (kg)			5561				5524
	Remaining metallic content		Mass (mM)(kg)	0				
Metals separtation (Mm)	Recyclable materials (mTr)							
	Technology no.		Name	Mass (mTr)(kg)				
		1	Glass rec	60				
		2	PUR	5				
		3	Composite	74				
		4	Elastomers	81				
Non-metallic residue treatment (mTr) and (mTe)	Total mass (mTr) (kg)			220				
	Energy recoverable materials (mTe)			Total Mass (mTe)(kg)				
	Remaining quantity of organic materials			427				
	Recyclability rate (Rcyc)			94%				
		mp		783				
		mD		5561				
		mM		0				
		mTr		220				
	Recoverability rate R(cov)			100%				
		mp		783				
		mD		5561				
		mM		0				
		mTr		220				
		mTe		427				

appendix 2: Calculation model of recycling ability of Volvo wheel loader L70 D. [Lindström H]

	Brandname	Volvo		Machine mass (ma) (kg)				
	Model (type/variant)	L70E		13070				
	Material breakdown	Metals	Polymers (excl elastomers)	Elastomers	Glass	Fluids	MONM	Others
		Mass (kg)						
		11002	125	10	65	196	3	736
			Mass (kg)					
Pretreatment (mp)	Fluids	mp1	196					
	Battery	mp2	60					
	Oil filters	mp3	12					
	LPG tanks	mp4	0					
	CNG tanks	mp5	0					
	Tyres	mp6	880					
	Cathalytic converter	mp7	0					
	Total mass (mp) (kg)		1148					
Dismantling (mD)	Partnumber	Name		(kg)	Metal content (%)			
	?	Engine		550	90			
	?	Transmission		457	90			
	?	Front axle		870	95			
	?	Rear axle		660	95			
	?	Boom cylinders		210	95			
	?	Starter motor		16	95			
	?	Alternator		7	95			
	?							
	Total mass (mD) (kg)			2770				
Metals separtation (Mm)	Remaining metallic content		Mass (mM)(kg)	8420,85				
Non-metallic residue treatment (mTr) and (mTe)	Recyclable materials (mTr)							
	Technology no.		Name	Mass (mTr)(kg)				
	1		Glass rec	65				
	2							
	3							
	4							
	Total mass (mTr) (kg)			65				
	Energy recoverable materials (mTe)			Total Mass (mTe)(kg)				
	Remaining quantity of organic materials (polymers, elastomers, MONM, etc)			138				
	Recyclability rate (Rcyc)			94,9				
		mp		1148				
		mD		2770				
		mM		8420,85				
		mTr		65				
	Recoverability rate R(cov)			96,0				
		mp		1148				
		mD		2770				
		mM		8420,85				
		mTr		65				
		mTe		138				

appendix 3: Trucks taken off road in Sweden 2002.

Vägverket

Antal fordon som har avregistrerats i vägtrafikregistret under 2002

Fordonsslag / orsak till avregistrering	Administrativt	Intyg	Saknas	Skrot	Utfört	Utgår	Övrigt	Summa
Personbil med totalvikt på högst 3 500 kg.	384	268 611	265	2	16 839	202	4 406	**290 709**
Personbil med totalvikt över 3 500 kg.		7			4		1	**12**
Lastbil med totalvikt på högst 3 500 kg.	94	15 194	29	1	1 579	62	452	**17 411**
Lastbil med totalvikt över 3 500 kg.	152	1 230	2	704	2 305		408	**4 801**
Buss med totalvikt på högst 3 500 kg.	2	39			69	4	7	**121**
Buss med totalvikt över 3 500 kg.	5	96	44		1 188		19	**1 352**
MC (oavsett totalvikt).	33	374		349	656	107	813	**2 332**
Motorredskap (oavsett totalvikt).	3	7		3	47	4	14	**78**
Släp (oavsett totalvikt).	93	1 128		1 797	2 053	55	2 791	**7 917**
Terrängskoter (oavsett totalvikt).	1	148		459	396	49	788	**1 841**
Terrängsläp (oavsett totalvikt).				2				**2**
Terrängvagn (oavsett totalvikt).	1	1		5	50	4	2	**63**
Traktor (oavsett totalvikt).	24	228		485	404	15	269	**1 425**
Summa	**792**	**287 063**	**340**	**3 807**	**25 590**	**502**	**9 970**	**328 064**

Förklaring till avregistreringsorsaken

Administrativt: - Fordon med minst tre års obetalda skatter, eller
- Avställda i minst tre år med minst tre års obetalda avställningsavgifter, och
- Inget ägarbyte har skett de tre senaste åren, och
- Ingen besiktning har skett inom de tre senaste åren.

Intyg: Skrotningsintyg från auktoriserad skrotare har utfärdats.

Saknas: Särskilda skäl (används som museiföremål, fordonet körts ner i ett vattendrag och därefter inte kunnat bergas, handling som visar att fordonet har skrotats i annat land mm).

Skrot: Fordon som förstörts eller att det genom annan åtgärd inte kommer att brukas i trafik.

Utfört: Fordon har varaktigt förts ut från Sverige.

Utgår: Fordon som är felregistrerade eller har dubbelregistrerats.

Övrigt: Fordon som byggts om till ett icke registreringspliktigt fordon, som har registrerats i det militära registret, som är stulna och inte har anträffats inom minst två år.

appendix 4: CPM DFR project brief description [CPM]

The aim of the project is to increase the knowledge of the manufacturing industry for the mechanisms that control how their discarded products are recycled. This knowledge can make it possible for the industry to develop more resource saving products and to get control of their costs related to producer responsibility. Furthermore, the aim is to contribute towards a common picture of the future for the manufacturing industry and recycling industry, which can increase the possibilities for the recycling industry of long term planning and investment in new processing techniques.

The objectives of the project are to:

- make a survey of the recycling market in Europe;
- present scenarios of future recycling markets and recycling systems;
- develop construction advice to simplify recycling of products, contribute towards cost efficient recycling processes, increase the value of recycled materials, and increase the recycling grade.

For detail description see http://www.cpm.chalmers.se at projects.

Appendix H

Volvo Car Corporation

Företagsnamn/Company name	Dokumentnamn/Name of document			Sida/Page
Volvo Car Corporation	Report			1 (6)6)
Utfärdare (avd nr, namn, tfn, geografisk placering, sign)/Issuer (dept, name, phone, sign)	**Datum**/Date	**Bilaga**/Appendix	**Flik**/Insert	**Reg nr**/Reg No
91710 Caroline Sjöberg +46 31 3255342 PVD	03-07-09	1		

Ärende/Subject

Glass Recycling

Mottagare (avd nr, namn, geografisk placering)/Receiver (dept, name)

Design for Recycling Project CPM

Material: glass

1. Description of the material

Glass consists of soda, lime and silica formulation. Additives may be magnesium oxide, aluminium oxide, zink oxide, lead oxide, arsenic trioxide, antimon trioxide, sodium nitrate or potassium nitrate. Colouring additives are oxides of copper, iron, nickel, manganese, chromium or cobolt. When it comes to recycling issues, glass can be divided into three different categories: flat glass, automotive glass and bottle glass.

Flat glass

Flat glass is used in architectural applications. Sometimes also automotive glass is referred to as a type of flat glass. In the context of recycling issues, however, flat glass from architectural applications differ from automotive glass.

Automotive glass

The biggest producers of automotive glass in Europe today are Pilkington, Saint-Gobain Vetrotex and Glaverbel. Automotive glass contains a plastic lamination film (windshields) or is hardened. It may also contain electrical wires made of silver or other metals.

Bottle glass

This fraction is divided into coloured and non-coloured glass. This is the fraction that has the highest rate of recycling today.

2. Which are the possible recycling technologies?

Trienekens Rohstoff GmbH & Co. in Nivenheim, Germany, is a part of RWE Umwelt which runs five glass recycling plants in the country. The Nivenheim plant is currently the largest glass recycling facitlity in the world.

At Nivenheim, bottle glass and automotive and architectural flat glass are treated. Up to 90% of the bottle glass is recycled for new bottle glass. The flat glass and automotive glass cannot be reprocessed for new flat glass because of quality issues. Recycled flat and automotive glass is disposed off to the following applications:

? Mineral wool industry

? Bottle glass industry

? Grinding products, glass beads, side rails

? Foam glass (small fraction, under development). Up to 80% of the foam glass on the German market is made of recycled flat/automotive glass.

Each year, 70 000 tons of flat/automotive glass are processed in the five RWE Umwelt plants. Half of the amount, 35 000 tons, is processed in Nivenheim.

The recycling of bottle glass in Sweden is carried out by Svensk GlasÅtervinning AB in Hammar. The company recycles approximately 150 000 tons of glass each year. During 2002, this corresponded to a recycling rate of 87% of all bottle glass. All non-coloured glass goes to production of new glass. Of the coloured glass, approximately 2/3 goes to glass producing companies and 1/3 to a company that produces glass wool. There is also a product called ”Microfiller”. It is finely ground glass that is used in concrete production. Microfiller gives positive features to the concrete.

Svensk GlasÅtervinning AB is completely dependant on fees from bottle producers. Therefore, they do not accept flat glass, automotive glass or glass from other applications.

Scandinavian Glass Recycling AB in Sweden are mainly specialised in recycling laminated glass, i.e. vehicle windshields. The company was started in 1998 in co-operation with the Swedish branch organisation for glass producers, Glasbranschföreningen. The windshields are collected in whole pieces and transported in specially adapted cages. At the plant, the windshields are crushed and the laminate is separated from the glass. The laminate is incinerated with energy recycling, whereas the glass is sent to a glass wool producer.

The business is partly financed through a small fee from the car owner/workshop/insurance company, but mainly from the sale of crushed glass to the glass wool producer. Scandinavian Glass Recycling AB recycled 118 000 laminated windshields from Sweden and 22 300 from Norway in 2002. They also accept other types of hardened or laminated glass or flat glass from other suppliers. The flat glass recycling part will probably expand during the autumn of 2003.

In Norway, Miljöteknologi Midt-Norge A/S in Meråker recycles light bulbs, fluorescent lights, bottle glass, flat glass and automotive glass. The glass is recycled into a glass foam that can be used in pavement of roads and sports grounds etc. For a detailed process description, please see appendix 1.

A company called Swede Glass United AB has recently started in Sweden. The company has made an estimation that there is 40 000 tons of flat glass per year to be recycled in Sweden. The company plans to collect glass from glass producers, car dismantlers and industry and export to Italy. Hardened, laminated, coloured and non-coulored flat glass as well as mirrors and insulation glass can be discarded in the same container. In Italy, the glass will be recycled into glass bottles but also into mosaic interior fittings for bathrooms and kitchens.

3. Waste fractions

? Flat glass.

? Bottle glass: is divided into coloured and non-coloured fractions. Should always be thoroughly cleaned.

? Automotive glass: is divided into two subcategories: laminated glass (windscreens) and hardened glass (side and rear windows).

For all fractions, it is important that they are clean from other materials.

4. Economic values (before and after processing/refinement)

Used and discarded glass is not a valuable product since there is no economical bearing in the recycling. Most recycling companies charge a gate fee for glass.

In Sweden, bottle glass recycling is financed through a fee collected from the producer through the so-called Producer Responsibility.

Recycling of automotive glass is financed in the same way, either through the scrapping reward that the customer receives from the Swedish authorities, or through a fee to the insurance company (in cases where the wind shield has to be replaced in a car that is not being scrapped). Since the entry into force of the ELV Directive, the recycling of automotive glass is to be financed by the passenger car producer. This only applies to vehicles <3500 kg.

The economic conditions for recycling of glass may become increasingly more favourable in the future. Considering the increasing costs for landfill, and the increasing efficiency of source sorting of waste, the prerequisites seem to get better and better.

5. Degree of efficiency (materialverkningsgrader)

The degree of efficiency is high (100%) in glass recycling processes. All input glass can be transformed into new glass, mineral wool or other. The waste fraction consists of pollutants such as ceramics, stones or gravel, light bulbs, electrical plugs, plastics, cork etc.

There is no limit as to how many times glass can be recycled. The limiting factor is the degree of collected glass for recycling as opposed to that sent for incineration, put to landfill or littered.

Using recycled glass in the production of new gives an energy saving of 20%.

6. Costs

Trinekes Rohstoff GmbH & Co. charges a fee of 10 Euro/ton automotive glass. At Miljöteknologi Midt-Norge A/S, the fee is SEK 200/ton laminated glass. They do not charge for non-laminated glass. The transport costs, however, have to be paid separately. Scandinavian Glass Recycling AB charges SEK 30 per windscreen (one windscreen weighs approx 12-14 kg).

Swede Glass United AB has a charge that is made up a basic fixed fee, to which two other fees are added. The first is a cost for transports and the second a variable cost that depends on the amount of glass to be recycled. The fees are agreed upon with each separate customer.

In Sweden, the glass bottle producers pay the following fees per produced bottle:

Volume (ml)	SEK
0-250	0,07
251-500	0,15
501-699	0,19
>699	0,28

Transport costs can be rather high considering the high density of glass.

7. Market actors

Actors in Sweden

? Glasforskningsinstitutet, Glafo www.glafo.se

? Svensk GlasÅtervinning AB, www.svenskglasatervinningab.se

? Glasbranschföreningen, GBF www.gbf.se

? Scandinavian Glass Recycling AB

? Swede Glass United AB, www.swedeglassunited.com

Actors in Europe

? Miljöteknologi Midt-Norge A/S http://www.hasopor.com/meraker.html

? GEPVP (European Association of Flat Glass Manufacturers) www.gepvp.org

Volvo Car Corporation

Företagsnamn/Company name	Dokumentnamn/Name of document			Sida/Page
Volvo Car Corporation	Report			6 (6)6)
Utfärdare (avd nr, namn, tfn, geografisk placering, sign)/Issuer (dept, name, phone, sign)	Datum/Date	Bilaga/Appendix	Flik/Insert	Reg nr/Reg No
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Ärende/Subject
Glass Recycling

Mottagare (avd nr, namn, geografisk placering)/Receiver (dept, name)
Design for Recycling Project CPM

Actors on the Global Market

? Strategic Materials, Inc. (the largest glass recycler and powdered glass processor in North America) www.stratmat.com

9. References

Reports/News letters

Visit to Glass-Recycling plant in Nivenheim of Trienekens Rohstoff GmbH & Co. KG (1/8/02),

HASOPOR NYTT, Nr 1 2003

Recycling of End-of-Life Vehicle Glazing, GEPVP

Samhällsekonomisk jämförelse av bring- och fastighetsnära system för insamling av glas, CIT Ekologik 2001

Internet sites

www.hasopor.com/meraker.html

www.nationalencyklopedin.com

www.ilrecycling.com

www.swedeglassunited.com

Personal contacts

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Mats Dahlman, Scandinavian Glass Recycling, tel. 044-10 20 11

Per Johansson, Svensk Glasåtervinning AB, tel. 0583-871 05

Per Sjöhult, Glasbranschföreningen, tel. 08 - 453 90 72

Ebbe Nyström, Swede Glass United AB, tel. 0583-102 08

10. Appendices

Appendix 1. Process description Miljöteknologi Midt-Norge A/S

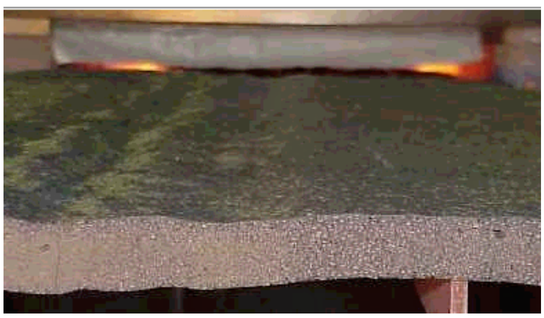
Miljöteknologi Midt-Norge AS, Norway
HASOPOR
Process description:
1. Sorting into different fractions.

- Fluorescent tubes and lamps. This fraction also contains powder consisting of, among other things, heavy metals such as Hg, Pb och Cd, ferrous and non-ferrous metals, fragments of paper, bakelite etc.
- Regular household glass (bottles, jars etc). Also contains ferrous and non-ferrous metals, fragments of paper, kork, Innehåller även magetiska och omagnetiska metaller, fragment av papper, cork, porcelain etc.
- Flat glass och automotive glass: contains the same materials as regular household glass

2. Vitrification
Powder mixed with glass particles is fed into a plasmareactor. Hg, Cd and Pb evaporate and follow the gases out of the reactor. The gas purification treatment system takes up the metals. Hg, which is the most volatile metal of the three, is bound by an activated carbon filter. Approximately 0,2% (by weight) of the feeding to the reactor is evaporated and collected in a filter. The other 99,8% of the feeding is tapped off the reactor and used as fluid glass in process step 3.

3. Glass foaming
Glass (10% purifired fluorescent lights and lamp bulb glass, 20-30% flat glass and 60-70% collected house hold glass) is mixed and fed into a large crusher. The glass is crushed into a fine powder, and moved out of the crusher with the help of suction. The glass powder is separated from the air jet with the help of a bag filter. The powder is mixed with an activating agent into a homogenous activated glass powder.

The powder is fed on a conveyor belt into a high temperature expansion oven. The powder is pre-heated, expanded and cooled in different steps in the oven. When it comes out of the oven, it has the form of foam glass, 2-3 times larger in size than the powder fed into the oven. The foam glass is called HASOPOR and consists of thousands of small, tightly located gas pores that are separated by thin glass walls. When the glass foam is cooled the tension in the material leads to a desintegration. The foam glass falls apart into a granulate materials with a grain size of 10-15 mm. Normally two different qualities of HASOPOR is produced, HASOPOR (180 kg/m3) and HASOPOR standard (225 kg/m3).



The edge of the glass foam

Appendix I

VOLVO

Volvo Car Corporation

Företagsnamn/Company name	Dokumentnamn/Name of document			Sida/Page
Volvo Car Corporation	Report			1 (5)
Utfärdare (avd nr, namn, tfn, geografisk placering, sign)/Issuer (dept, name, phone, sign)	Datum/Date	Bilaga/Appendix	Flik/Insert	Reg nr/Reg No
91710 Caroline Sjöberg +46 31 32 55 342 PVD	04-03-09	1		

Ärende/Subject

PVC Recycling

Mottagare (avd nr, namn, geografisk placering)/Receiver (dept, name)

Design for Recycling Project CPM

Material: PVC (Polyvinyl chloride)

1. Description of the material

PVC, Polyvinyl chloride, is a thermoplastic which differs from other thermoplastics by containing chlorine. The chlorine stands for around 56% of the weight of the PVC molecule. PVC is rather heavy (1,4 g/cm3), and without a plasticiser stiff (modul 2,5 GPa), strong (tensile strength of 50 mPa) and has high impact strength.

PVC has an advantage compared to other plastics in that it easily mixes with additives such as plasticisers, stabilisers etc. This gives the material a wide range of use. It can be used for rigid products such as pipes, profiles, window frames and for soft products such as cable insulation, floor mats and vehicle interior materials.

However, PVC has some environmental disadvantages compared to other plastics. Leakage of heavy metal stabilisers and the formation of dioxin when incinerated, are issues that have been discussed. The vinyl chloride monomer, the basic building block of PVC, is a carcinogen and can cause cancer when breathed in high concentrations over a long period of time. The environmental characteristics of PVC imply that focus should lie on finding suitable recycling technologies for this material. Its characteristics also imply a high melting viscosity, which complicates the recycling process.

2. Which are the possible recycling technologies?

Mechanical recycling

Mechanical recycling can be carried out using post-use PVC products that are easy to identify and separate from the waste stream. They should also be clean. Examples of products that can be recycled are bottles, flooring, pipes, roof covering membranes and window profiles. All of these can be closed-loop reycled into the same products except for roof covering membranes, which become water proofing liners. Bottles can also become pipes, profiles, fittings, sweaters and shoe soles.

PVC composites can sometimes be recycled. Examples of products are industrial flooring and "leather cloth", which can be recycled into moulded mats and carpet backings, respectively.

Feedstock recycling

Feedstock recycling is better suited for complex products than mechanical recycling and should be seen as a complement. Examples of products that can be recycled with this technology are laminated films, "leather cloth", footwear and car dashboards.

For waste that is low in chlorine content: The pre-treatment steps include sorting or separation which is done by dilution of excessive chlorine or thermal dehalogenation.

The second step is "thermal cracking" via hydrogenation, pyrolysis or gasification. The produced hydrochloric acid is neutralised or separated for industrial use.

For waste that has a high chlorine content (>30%), the process is different. These processes are still in early development and include high temperature incineration in a rotary kiln, gasification in a metal or slag bath, or pyrolysis in a circulating fluidised bed. The HCl output has to be purified so that it can be used for making new PVC. The economic viability of these processes are still somewhat insecure.

The European PVC industry, represented by The European Council of Vinyl Manufacturers (ECVM), European Plastics Converters (EuPC), The European Council for Plasticisers and Intermediates (ECPI) and The European Stabilisers Producers Associations (ESPA), has started a co-operation called Vinyl 2010. The project works together with the voluntary commitment of the European PVC Industry, which, among other things, has embarked on a 10-year plan to enhance its sustainability profile by improving production processes and products, investing in technology, minimising emissions and waste and addressing collection and recycling issues.

<u>Denmark – Stigsnaes</u>

As a part of Vinyl 2010, Stigsnaes and RSG 90 are developing a chemical recycling plant for PVC in Denmark. The process includes hydrolysis of the PVC and the products are gas/oil, charcoal and NaCl. De-chlorination can be carried out down to 0.1% weight of chlorine.

The process is carried out in five units: 1) sorting and shredding, 2) hydrolysis, 3) separation, 4) varming and conditioning and 5) salt recycling unit. The hydrolysis step is an exotermic process which implies that it only needs a little energy when started, after start-up the process runs by itself.

Maximum permitted amount 150 000 tonnes of PVC waste per year, calculated capacity approx 123 000 tonnes PVC waste per year. Maximum amount unknown materials in the PVC waste is 5%. Expected production capacity is approx. 29 000 tonnes of gas/oil, 50 000 tonnes of coke and 38 000 tonnes of NaCl per year. Other by-products are iron and metals, approx. 2500 tonnes per year, stones and building waste, approx 2500 tonnes per year, and other plastics, 5000 tonnes per year.

The PVC waste should be shredded in sizes of 100-150 millimetres before arriving to the plant.

<u>Italy – Solvay</u>

The VINYLOOP recycling process for composite PVC scraps is commissioned at industrial scale at Ferrara (Italy since February 2002. By December 2002 more than 412 tonnes of recycled PVC from post-consumer electrical cable waste had been sold. The objective was to reach a recycling rate of 750 tonnes per month during 2003.

From the recycled PVC, several different products can be made: sweaters, bottles, pipes, road barriers, tunnel construction etc.

<u>Germany - DOW</u>

Dow started a trial feedstock recycling plant in Leipzig, Germany, that recycles high-chlorine waste. In March 2003, a supply of 2010 tonnes of mixed PVC waste was processed. The recovered chlorine was used on-site for production of new VCM/PVC production.

<u>The Netherlands - Redop Process</u>

The Redop process in the Netherlands has been developed to deal with the mixed plastic segment of municipal solid waste. The waste is de-chlorinated and then fed into blast furnaces for steel production, together with coal.

Trials were carried out in 2001 with good results. During 2002 tests continued, with objective to run on an industrial scale during second quarter of 2003. This objective was met by quarter 4, 2003.

<u>Watech</u>

The NKT-Watech process consisted of a two-step pyrolysis process in a stirred vessel. The project was to be carried out in a 1m3 scale pilot plant, and requested for financial support to scale up to a commercial process. However, due to the development of the Stigsnaes project and taking into consideration the total amount of available PVC waste in Denmark, no financing could be found. Later, the company was purchased by RGS 90.

<u>Tavaux</u>

A pilot plant was built and started in Tavaux in France, the project carried out by an industry partnership lead by ECVM. The process is based on slag bath gasification technology. A trial period started in the end of 2000, and after some initial problems and corrective actions, the trials could be continued. The programme was to be completed in 2002, and the results were to form a basis for decision on whether to expand the project to a commercial scale.

3. Waste fractions

The PVC waste can be divided into several different fractions, depending on what technology is chosen for recycling. PVC containing lead/cadmium/zinc or other stabilisers has to be treated separately and feedstock recyling is necessary. Old PVC with unknown contents should also be recycled this way.

Mixed municipal waste containing PVC has to be treated separately. Clean PVC waste with well-known contents can be recycled mechanicallly.

4. Economic values (before and after processing/refinement)

No information is available on the economic prerequisites for PVC recycling.

5. Degree of efficiency (materialverkningsgrader)

The degree of efficiency of the processes can not easily be calculated. It depends completely on the recycling process chosen and the PVC content of the incoming waste, as well as the composition of the PVC.

6. Costs

The gate fee for PVC waste at Stigsnaes is 200 Euro/tonnes of waste. RGS90 bare hoping to be able to reduce the gate fee in the future.

7. References

Reports/News letters/Other publications

Slapak, M.J.P, van Kasteren, J.M.N, Drinkenburg, A.A.H., Design of a process for steam gasification of PVC waste, Resources, Conservation and Recycling 30 (2000), 1999

Miljögodkendelse til RGS 90 PVC-Recycling, Skaelskör Kommune, 2003

PVC and the Environment, Norsk Hydro 1992

Internet sites

http://www.elsevier.com/wps/find/journaldescription.cws_home/404/description#description
http://www.plast-kemi.se/pvc/index.htm
www.plastkemiforetagen.se
www.vinyl2010.com
www.plastinformation.com
www.plastics-in-elv.org
www.solvay.com
http://www.vinyloop.com

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Appendix J

Recycling information about different composites

By Ylva Larsson, Bombardier Transportation, 2004-09-06
3EST 7-3058

Recycling information about SMC, Sheet Moulded Compounds

SMC, Sheet Moulded Compounds, and BMC, Batch Moulding Compounds, are thermoset plastics reinforced with glass fibres and fillers. The plastic is cured to its final shape and after the curing, the plastic is not remeltable. The most common plastic is polyester. Epoxi, vinylester and acrylates are also used. SMC is the most common composite type, the volumes are much greater than carbon fibre reinforce plastics (CFRP). The glass fibre content normally varies between 25 to 55 w%. The manufacturing process gives suitability for rel. small parts with big series production. In most applications it is possible to save 20 to 50 w% compared to steel constructions.

GRP stands for glass fibre reinforced plastics and FRP stands for fibre reinforced plastics, most often the fibre is glass. World production of FRP is ca 4.2 million tons per year (ReFiber).

The automotive industry is the biggest user of this material group (where SMC is much more common than the courser parts that are classified as BMC) and boats and wind mills are other big users. The life length is predicted 10 - 50 years and big amounts of post-consumer composite waste are expected soon. So far small amounts have been material recycled, e.g. by ERCOM, and many methods are practically possible but the economical feasibility has not been demonstrated.

The biggest problem is the lack of demand to use the recycled composite in a new application. Different possibilities to recycle SMC are presented in Table 1.

Recycling information about GMT, Glass Mat Reinforced Thermoplastic

GMT, Glass Mat Reiforced Thermoplastic, is a thermoplastic matrix (e.g. PP, PA, PET) reinforced with orientated or random glass fibres of various length. The biggest use are within the automotive industry; frames, front parts etc. It is often manufactured with pre-pregs that are heated and moulded, or with plastic granulates and glassfibres that are mixed with additives and heated and moulded. VAMP18 project looked at the recycling of production waste (http://www.mtov.lth.se/vamp18/). Post-consumer waste are harder to material recycle due to less knowledge of material content and properties, but it is not impossible. Different possibilities to recycle GMT are presented in Table 2.

Recycling information about PP/Flax

PP/flax is polypropylen thermoplastic reinforced with flax fibres. The use of this material has increased since it has good mechanical properties and are renewable, biodegradable and combustible. Flax is *lin* in Swedish. Different possibilities to recycle PP/Flax are presented in Table 3.

Recycling information about CFRP, Carbon Fibre Reinforced Plastics

CFRP, Carbon Fibre Reinforced Plastics are used when materials need to combine high strenght with low weigh (aircraft, space and yacht designing). The carbon fibres are about 10 times as expensive as glass fibres, but the constructions can be made lighter. Thermosets are used as matrix and epoxi or vinylester is most common plastic to use as matrix. Since the raw materials are more expensive, the driving forces to recycle the composites should be higher, but the CFRP waste fractions have probably not been large enough yet. Different possibilities to recycle CFRP are presented in Table 4.

Recycling information about sandwich composites

Sandwich constructions are used in many applications, mainly in aircraft and space industry but also for marine constructions and train applications. They are made of two thin, strong faces bonded (with adhesive or welding) to a weaker flexible core. The faces carry the compressive and tensile stresses that arise in bending. The core caries the shear stresses and keeps the faces at constant distance. This leads to that the sandwich derive outstanding bending strength and flexural stiffness, combined with low weight. The faces can be fibre reinforced plastics, plywood or metal sheet. The core can be made of a rigid polymer foam, a honeycomb structure or balsa wood for example. The weakest spot is the adhesive bonding between the faces and the core; if delamination occurs the construction loose its strength. Techniques to do reinforcement in the core connected to the faces without any joints, removes this problem.

The core in the sandwich can contain a high fraction of recyclate. SICOMP made a boat in the middle of 90's to demonstrate the recyclability of thermoset composites. The faces of glass fibre reinforced polyester contained a part of recyclate and the core was a polyester based mixture containing 33-40 % ground scrap. That gave a content of about 20 % recycled material. This was a prototype and limited interest on the market stopped series production. SICOMP has also developed RECYCORE - a glass fibre reinforcement based on recovered composit waste. The two surface layers are conventional glass fibre reinforcements. The core contain the recyclate, and the amout can be varied between 10 to 70 % by weight.

Mechanical material recycling of sandwich FRP composites is possible but the amount of SMC waste not bonded to a core is so much greater and easier to recycle (and this still does not happen to large extent) so this scenario seems unlikely.

Different possibilities to recycle sandwich composites are presented in Tables 5 and 6.

Table 1 – Presentation of different possibilities to recycle SMC

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**	**Chemical recycling**
Status	Existing process but decreasing activity due to little demand to use the recycled material. ERCOM GmbH was active 1990-2002. About 400 tons per year were shredded, mostly from production scrap and post-consumer parts from service operations. 300 tons was recycled into new SMC/BMC products and I00 tons was used in the concrete industry. The capacity was 4000-5000 tons per year (ERCOM).	Happens probably a lot, especially for smaller parts mixed with other waste	Existing process, but limited activity. Capacity of 5000 tons per year at Holstebro, Denmark. Small scale recycling at University of Nottingham, UK. The conclusion of Nottingham though, is that carbon fibre reinforced products are more economically feasible to recycle this way than glass fibre reinforced plastics, since the virgin carbon fibres are 10 times more valuable than glass fibre and the carbon fibres do not degradate as much in tensile stengt during the process, se CFRP	Only in theory
Raw material in	Dismantles and sorted composite waste in pieces. Only experiences from glass fibre reinforced *polyester* (the most common composite)	Composite waste	Composite waste	
Raw material out	Particle-like material which can be used as filler or reinforcement in virgin products. To use as reinforcement is more cost efficient than to use the material as filler. (VAMP18)	Energy. Ash	Energy + Glass fibres	
Other	Mobile shredder possible, the shredded waste (reduced volume by a factor 4) is transported to a fractionizing plant where there is possibility to grind the material in a closed system, dust-free, to different fractions	Ash content depends on glass fibre content. The glass melts at ca 850 degrees and too big amounts of glass in an incineration plant, especially a fluidised bed, can lead to big difficulties. The incineration plant decides how big fraction they can accept. The heat value varies with glass content. Normal values of the composite waste are 8-11 MJ/kg. (Household waste have normally around 11 MJ/kg) (VAMP 18)	450 - 500 deg C. No oil production, but gasification of plastic parts. All plastics can be recovered, but PVC is not accepted due to that the cleaning of the flue gases gets more expensive	
Surface treatment		Not important		

Table 1 (cont.) – Presentation of different possibilities to recycle SMC

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**	**Chemical recycling**
Impurities	impurities and additives, e.g. heavy metals will, if present, be transferred to the recycled product	Will be transferred to the ash	Glass fibres will be more sensitive with increased process temperature	
Age of the material	Not important, but the resin must be fully cured to prevent emissions of e.g. styrens	Not important	Not important	
Form	Not important but not too big	The size of the composite part should no be too big/thick/dense (not over 0.5x0.5 m) (VAMP 18)		
Other properties	Occupational maximum exposure limits for fibre particles in air must be complemented with personal protection in order to establish an appropraite working environment. (VAMP 18)			
Value before converting/ refining process	Negative	Negative	Negative, charge of 200 Euro/ton	
Value after converting/ refining process			Positive, 20 Euro/ton income from selling of the short fibre glass product. Can be used as filler, as fibre reinforcement in new composites or in asphalt, in insulation materials and raw material for Boron glass production	

Table 1 (cont.) – Presentation of different possibilities to recycle SMC

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**	**Chemical recycling**
Comment	Collecting, sorting and dismantling is expensive, often made by hand in Asia and in USA (by prisoners). Small volumes compared to other waste streams. An advantage is that most of the tensile strength of the glass fibre is retained. Disadvantage is that end-product contains a mixture and that the end-product has low value, the fillermarket is flooded with similar products (SICOMP). To maximise the cost and environmental benefit (short) glass fibres should be replaced by the recycled material when producing new composites (VAMP18).	Not classified as material recycling. Not environmentally beneficial if e.g. building waste with large wood content is replaced (VAMP18). Related methods are fuel in cement production where the glass can be a part of the final product or to use the composite waste in steel production	Advantages are that the end-product is very homogeneous and that the energy content of the plastic part is recovered. Disadvantages are that the glass fibres loose a considerable part of their original tensile strength and it is yet not determined if this method will be classified as 100 % material recycling of the composite	High cost of plant, aggressive and hazardous chemicals needed, expensive cleaning of fibres
Reference	ERCOM 2002 SICOMP 2003		ReFiber ApS, DK University of Nottingham, UK	

Table 2 – Presentation of different possibilities to recycle GMT

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**	Chemical recycling
Status	Not common for post-consumer waste		Should have same possibilities as SMC waste, but no statistics available. Capacity of 5000 tons per year at Holstebro, Denmark. Small scale recycling at University of Nottingham, UK. The conclusion by nottongham though, is that carbon fibre reinforced products are more economically feasible to recycle this way than glass fibre reinforced plastics. The virgin carbon fibres are 10 times as valuable than glass fibre and the carbon fibres do not degradate as much in tensile stengt during the process, se CFRP	
Raw material in	Production waste	Composite waste	Composite waste	
Raw material out	Granulates	Energy. Ash	Energy + Glass fibres	
Other	A way to save raw material in production. Known material composition	Ash content depends on glass fibre content. The glass melts at ca 850 degrees and too big amounts of glass in an incineration plant, especially a fluidised bed, can lead to big difficulties. The incineration plant decides how big fraction they can accept. The heat value varies with glass content. Normal values of the composite waste are 25-30 MJ/kg. (Household waste have normally around 11 MJ/kg) (VAMP 18)	450 - 500 deg C. No oil production, but gasification of plastic parts. All plastics can be recovered, but PVC is not accepted due to that the cleaning of the flue gases gets more expensive	
Impurities		Will be transferred to the ash	Glass fibres will be more sensitive with increased process temperature	
Age of the material		Not important	Not important	
Form		The size of the composite part should no be too big/thick/dense (not over 0.5x0.5 m) (VAMP 18)	Not important	

Table 2 (cont.) – Presentation of different possibilities to recycle GMT

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**	Chemical recycling
Other properties	Occupational maximum exposure limits for fibre particles in air must be complemented with personal protection in order to establish an appropraite working environment. (VAMP 18)			
Value before converting/ refining process		Negative	Negative, charge of 200 Euro/ton	
Value after converting/ refining process			Positive, 20 Euro/ton income from selling of the short fibre glass product. Can be used as filler, as fibre reinforcement in new composites or in asphalt, in insulation materials and raw material for Boron glass production	
Comment	Both cost and environmental benefits when production waste is recovered recycled. The benefits depends on which virgin material that is replaced (VAMP 18)	Not classified as material recycling. Gives environmental benefits when fossil fuels are replaced. Not environmentally beneficial if e.g. building waste with large wood content is replaced. Promising result to mix 10 % grinded composite waste with 90 % wooden chips into pellets (VAMP18)	Advantages are that the end-product is very homogeneous and that the energy content of the plastic part is recovered. Disadvantages are that the glass fibres loose a considerable part of their original tensile strength and it is yet not determined if this method will be classified as 100 % material recycling of the composite	High cost of plant, aggressive and hazardous chemicals needed, expensive cleaning of fibres
Reference			ReFiber ApS, DK University of Nottingham, UK	

Table 3 – Presentation of different possibilities to recycle PP/flax:

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)
Status	production waste (?)	Not an identified waste stream
Other		Heat value is between 35 and 40 MJ/kg (more than 3 times higher than municipal household waste). It is comparable to fuel oil.
Other properties	Occupational maximum exposure limits for fibre particles in air must be complemented with personal protection in order to establish an appropraite working environment. (VAMP 18)	
Value before converting/ refining process		Negative?
Comment	Not much data on this	Gives the most environmental benefits, good to produce pellets for combustion (VAMP18)

Table 4 – Presentation of different possibilities to recycle CFRP:

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**
Status	?		University of Nottingham, UK
Raw material in			CFRP waste
Raw material out			Energy + carbon fibres
Other		Heat value is just above 30 MJ/kg, higher than GRP products and almost 3 times higher than municipal household waste. Both temperature and oxygen should be as high as possible and the material should be separated into small pieces in order to achieve complete combustion (VAMP18)	Recovery of plastic parts (pyrolysis/gasification). The carbon fibre tensile strength is only 20 % decreased at processing temperature of 450 deg C. Can be used in moulding compounds (Nottingham)
Form		The size of the composite part should no be too big/thick/dense (not over 2x2 dm, especially important for prepregs) (VAMP 18)	

Table 4 (cont.) – Presentation of different possibilities to recycle CFRP:

Type of process	**Material recycling** (mechanical material recycling)	**Energy recovery** (Incineration of the composite waste with or without other fuels)	**Material recycling with energy recovery**
Other properties	Occupational maximum exposure limits for fibre particles in air must be complemented with personal protection in order to establish an appropraite working environment. The electrical leading properties of emitted carbon fibres needs to be taken into consideration. (VAMP 18)		
Value before converting/ refining process		Negative	Negative
Value after converting/ refining process			Theoretical value of 15000 Euro/ton carbon fibre (Nottingham)
Comment	To replace virgin carbon fibre with recycled CFRP gives both cost and environmental benefits (VAMP18)		Advantages with this recovery method are that the end-product is very homogeneous and that the energy content of the plastic part is recovered. This recovery method is promising since carbon fibre are much more valuable than glass fibre and no recycling processes are really available today. Aerospace industry needs to address the recycling issue and carbon fibre is potentially useful for lightweight/fuelefficient automobiles. Not yet determined if this can be classified as 100 % material recycling.

Table 5 – Different possibilities to recycle different sandwich composites:

Material	GRP/PVC foam	GRP/foam or balsa	CFRP/PVC foam	CFRP/foam or balsa
Type of process	?	Material recycling with energy recovery	Material recycling	Material recycling with energy recovery
Status		Existing in small scale. Capacity of 5000 tons per year at Holstebro, Denmark. Small scale recycling at University of Nottingham, UK.	?	?
Raw material in		Composite waste	Composite waste	Composite waste
Raw material out		Energy + Glass fibres	PVC + Carbon fibres	Energy + Carbon fibres
Other		450 - 500 deg C. No oil production, but gasification of organic parts. PVC is not accepted due to that the cleaning of the flue gases gets more expensive	Separation of faces, material recycling of PVC and recovery of carbon fibres, see CFRP	Recovery of plastic parts (pyrolysis/gasification). The carbon fibre tensile strength is only 20 % decreased at processing temperature of 450 deg C. Can be used in moulding compounds (Nottingham)
Impurities		Glass fibres will be more sensitive with increased process temperature		
Age of the material		Not important		
Form		Not important		
Value before converting/ refining process		Negative, charge of 200 Euro/ton		Negative
Value after converting/ refining process		Positive, 20 Euro/ton income from selling of the short fibre glass product. Can be used as filler, as fibre reinforcement in new composites or in asphalt, in insulation materials and raw material for Boron glass production		Theoretical value of 15000 Euro/ton carbon fibre (Nottingham)

Table 5 (cont.) – Different possibilities to recycle different sandwich composites:

Material	**GRP/PVC foam**	**GRP/foam or balsa**	**CFRP/PVC foam**	**CFRP/foam or balsa**
Type of process	?	Material recycling with energy recovery	Material recycling	Material recycling with energy recovery
Comment	Common in windmill, boats. Not much recycling data available	Common in windmills, boats, train fronts. Advantages with this recovery method are that the end-product is very homogeneous and that the energy content of the organic part is recovered. Disadvantages are that the glass fibres loose a considerable part of their original tensile strength and it is yet not determined if this method will be classified as 100 % material recycling of the composite	Common in yacht construction, aircraft and space applications. Not much recycling data available	Common in yacht construction, aircraft and space applications. Advantages with this recovery method are that the end-product is very homogeneous and that the energy content of the organic part is recovered. This recovery method is promising since carbon fibre are much more valuable than glass fibre and no recycling processes are really available today. Not yet determined if this can be classified as 100 % material recycling.
Reference		ReFiber ApS, DK	University of Nottingham, UK (but separation of PVC not verified) DIAB	

Table 6 – Different possibilities to recycle different sandwich composites:

Material	**Metal/foam**	**Metal/foam**	**Metal/metal honeycomb**	**Organic composite (e.g. plywood + foam**
Type of process	Material recycling	Material recycling and energy recovery of foam	Material recycling	Incineration with energy recovery
Status	?	Happens normally today (maybe not the energy recovery of the foam..)	Happens normally today, no problems	Should happen normally today, no problems
Raw material in	Composite waste	Composite waste	Metal waste	Organic waste
Raw material out	Recycled metal + foam parts	Recycled metal + energy	Recycled metal	Energy
Other	Theoretically it is possible to tear off the skin off the core. Then it is possible to recover the core material and use it in other products	Shredding and separation in a hammer mill. Recovery of metal after normal procedures and recovery of the foan together with the other combustible shredder residues		
Value before converting/ refining process	Positive of metal Negative of foam	Positive of metal Negative of foam	Positive	Negative
Comment	Design concept for passenger trains, developed at Bombardier Transportation and KTH. FICAS consist of stainless steel sheet bonded to PMI foam	Design concept for passenger trains, developed at Bombardier Transportation and KTH. FICAS consist of stainless steel sheet bonded to PMI foam	Used in different constructions where weight-saving is crucial	
Reference	Bombardier Transportation	Bombardier Transportation		

Appendix K

VOLVO

ER 59957

Engineering Report

Date	Report Type
2004-06-28	Misc.

Receiver (department, name, location)	Requisition/order no.	Project no.	Secrecy level
00000 Rolf Willkrans, VHK CPM/Chalmers University of Technology Department of Physical Resource Theory Ulrika Lundqvist		10474302	4

Function group no.	Analysis no.

Ordered by (department., name, location)
00000 Rolf Willkrans, VHK
Issued by (department, name, location)
6700, Katarina Heikkilä, M1.4
Approved by (department, name, location)
6700, Annika Gunnarsson, M1.4

Approval date	Date carried out	No of Pages	No of Appendices
2004-06-28	05-06/2004	9	-

Advanced Engineering Area	Key Technology Area	Property Area
		Environmental and life cycle assessment

Hazardous substances in materials of trucks

Abstract

The aim of this study is to identify the hazardous substances in component materials for trucks that ought to be avoided from the shredding, and from further recycling and recovery processes. Hazardous substances are substances that according to valid legislation may be expected to lead to injury of human being or damages on the environment.

The occurrence of the hazardous substances in the component materials of trucks may be an obstacle in the recycling or recovering processes in the disposal stage of trucks. Metals are the main component materials of a truck, since they form 83 % of its total weight; plastics contribute with 6 %. In metals, the hazardous substances can be found, in limited amounts, as alloy substances, as well as in batteries for trucks. In production of plastics, the hazardous substances are used as additives, softener, pigment, or flame-resistant agent.

To reduce the accumulation and further spread of hazardous substance in the environment, the hazardous substances should be replaced already in the production processes of component materials of trucks by better environmental alternatives.

Contents

1 Introduction

This report is a part of the project “Design for recycling” (DfR), coordinated by CPM, at Chalmers University of Technology in Gothenburg. The main objective of the project is to lay basis for design guidelines of future vehicles with respect to their effective recycling and recovery in the disposal stage of the life cycle.

The aim of this study is to identify the hazardous substances in component materials for trucks that ought to be avoided from the shredding, and from further recycling and recovery processes related to trucks.

2 Method

Through a literature survey, the various hazardous substances, the legislation about their use, possible limitations, and phase-out strategies are identified. Further analysis is focused on substances that occur in the materials typical for the production of trucks, and which can be harmful to the manufacturing processes, or the quality, of the new materials produced from the scrap.

3 Hazardous substances

Hazardous substances are substances that according to valid legislation may be expected to lead to injury of human being or damages on the environment [1].

The “Non - toxic environment” [2] is one of the 15 environmental quality strategies adopted by the Swedish Parliament. This strategy covers hazardous substances and their phase-out strategies. According to this objective, the substances that are considered to be especially harmful are to be phase-out according to a given time schedule.

The following substances and groups of substances are identified to be necessary to phase out [2]:

- CMR substances (substances that cause cancer, are mutagen and disturb the reproduction process);
- PBT substances (persistent, bio-accumulative and toxic substances);
- vPvB substances (very persistent and very bio-accumulative substances);
- mercury (Hg);
- cadmium (Cd);
- lead (Pb).

Furthermore, according to this Proposal [2], the risks for human health or the environment from chemicals that are not covered by the phase-out strategies should be continuously reduced. To this group of chemicals belong all substances covered by directions KIFS 1994:12 [3] of the Swedish Chemical Inspectorate, that regulates the classification and marking of all chemicals before their introduction to the market.

4 Hazardous substances and trucks

In the automotive industry, the hazardous substances occur in the production of vehicles, in products intended for the after-care of the completed vehicles, or in the vehicle itself as a part of component materials. Therefore, recommendations and possible restrictions about each of the hazardous substances have to take into account in what circumstances the hazardous substance occurs. For example, the restrictions about the use of a substance which is harmful to the human health may be differentiated based on the fact if the substance is used in a production process with a possible exposure to workers or not.

However, the aim of the Design for Recycling project is to formulate guidelines for designers on how to design the vehicle with focus on the end of life of the vehicle. Therefore, hazardous substances occurring in the production processes and aimed for after-care of vehicles are not taken into account, and the study focuses on substances in component materials of trucks.

4.1 Metals

Various metals are the dominant component materials of a truck. According to Klintbom and Wahlström [4], for example, the truck 2285 T03C consists, approximately, of 83 % of metals such as steel (39,5%), iron (38,2 %), aluminium (3%), lead (1,4%), and brass, bronze, and copper (0,5%), 6 % of plastics, and the rest 11 % of other materials. Consequently, metals, particularly steel and iron, form also the dominant part of the scrap in the disposal stage of the truck.

Before delivering to a shredder facility, all steel and iron scrap should be free from irrelevant materials [1]. Examples on such irrelevant materials, with connection to the automotive industry, are:

- Scrap with risk to explosion (e.g. small bumpers of passenger cars),
- Scrap with coating of chromium, nickel and zinc,
- Scrap painted by paints containing lead,
- Batteries,
- Hazardous chemical substances/products.

<u>STEEL</u>

Steel, similarly to other metals, can be recovered unlimited number of times without any negative impacts on the quality of the new product. The recovery processes have positive environmental effects due to lower use of virgin material. Moreover, production of steel from scrap to a ready to use product is simpler and shorter than the production from ore. This also implies lower production costs [1].

Steel can be produced in a number of various qualities depending on its intended application. The quality of steel is improved by adding various substances in the alloy. Substances that are often used are for example chromium (Cr), nickel (Ni) and molybdenum (Mo). These substances may cause problems for certain sorts of steel [5].

It is not desirable that steel containing alloying metals is mixed with the average steel scrap. Firstly, the substances are too valuable to be mixed up with an average scrap, and thus cannot be reused in a proper way. Secondly, the substances can be harmful for the quality of the steel to be produced from the scrap. For example, copper is a substance that may have a significant negative impact on the quality of the steel. However, steel scrap of various qualities is today possible to recover by processes appropriate for the quality of the scrap under the condition that the scrap is well sorted.

In a truck, the dominant part of the steel products is produced from cold/hot rolled steel, and from galvanised steel containing zinc (Zn). Only small parts are produced from various steel alloys. Furthermore, boron (B) is also used as a substance of alloying materials for steel. Some compounds of boron are classified as CMR substances and therefore should be replaced according to the Swedish environmental objective “A non-toxic environment”.

Boron (B), besides copper (Cu), lead (Pb), mercury (Hg), and bismuth (Bi), belongs to the substances that are harmful to the new-produced steel, since they have impact on its quality.

IRON

In a truck, iron is represented in about the same proportion as steel, i.e. 38.2 %. The iron used is a graphite iron which contains, besides the basic substances for iron, also small amounts of copper (Cu) and manganese (Mg).

LEAD

Lead is used in the truck as a component material of the battery. Lead is one of the hazardous substances that have to be phased-out.

PLATINUM

Platinum is the metal, that has been introduced in the automotive industry as a component material in the new type of the after-treatment exhaust system known as Selective Catalytic Reduction (SCR). The SCR systems are developed to meet the future requirements on the emissions from exhaust gasses (mainly NOx and particles). Although the amounts of platinum used are small, the metal should be recycled since platinum is classified as a scarce resource.

4.2 Plastics

The use of plastics as a component material in a truck continuously increases. One of the positive effects of use of plastics is their contribution to the reduction of the total weight of trucks and thus to the reduction of fuel use.

Nevertheless, in production processes of plastics, various hazardous substances are often used; for example CFC (chlorofluorocarbons) used in manufacturing of foam plastics. Hazardous substances are often used also as additives for the different plastics, as softener, pigment, flame-resistant agent, etc. The kind and the amount of the specific substances varies for the different plastic materials.

The occurrence of the hazardous substances may be an obstacle in the recycling or recovering processes in the disposal stage of plastics. Moreover, the marking of the specific plastic material is often missing. This leads consequently to a significant risk, that the hazardous substances will be, through the recycling or recovering processes, leaking to the environment, or that they may cause reactive processes of other undesirable substances or compounds released to the environment.

5 Tools for the practical work with hazardous substances

There is a number of various substances and their compounds that are classified either as hazardous, or toxic. Therefore, practical tools have been developed to facilitate the work with these chemicals.

5.1 The Swedish Chemical Inspectorate

The Swedish Chemical Inspectorate is a supervisory authority under the Ministry of the Environment which enforces national as well as EC – legislation. The Inspectorate has developed several tools that are accessible on the Web.

PRIO guide

The PRIO [6] is developed by the Swedish Chemical Inspectorate, and replaces the former list known as the Observation (OBS) list. PRIO, similarly as the OBS list, is intended for assessment of risks to human health and the environment from chemicals. The substances included in the PRIO guide are assessed in accordance with the environmental quality objective “A non-toxic environment” [2].

The Restricted Substances Database

The Restricted Substances Database, developed by the Swedish Chemical Inspectorate [7], contains information about the restrictions, according to regulations issued by the Swedish governments or the Swedish Chemicals Inspectorate, related to a substance or group of substances. The Restricted Substances Database replaces the former Restriction list.

5.2 Volvo

Besides the lists of the Swedish Chemical Inspectorate, there is a number of lists specifically developed and suited for usage within a company. For example, the Volvo Group’s Environmental Council decided to implement specific lists that limit the use of a number of chemicals. The lists are based on the current legislation about hazardous substances, and the official lists of the Swedish Chemicals Inspectorate [5, 6]. Volvo-specific requirements are formulated to prohibit, limit or suggest a substituting alternative to the substances, and thus reduce the health and environment risks related to the specific use of the hazardous chemicals. Three different lists are presented:

- The **Black list** [8], which includes chemical substances that must not be used within the Volvo Group;
- The **Grey list** [9], which lists the chemical substances that should not be used within the Volvo Group;
- The **White list** [10], which covers chemical substances and the corresponding production processes that may be critical from a health and environment point of view, and suggests alternatives that are potentially less harmful.

The lists are continuously updated, taking into account new knowledge about the various chemical substances, as well as legislation.

LIMIT

The Listed Materials Inventory Tool (LIMIT) [11] has been developed to facilitate work of designers and purchasing departments within the Volvo Group companies with the implementation of the Black and Grey lists. In the LIMIT, the probable application and occurrence of hazardous substances and listed on the Black and Grey lists is described, as well as their effects to the human health and to the environment.

Standard for marking of plastics products

Volvo Group has developed a standard for marking and designation of plastics products [12]. The standard is based on the international standard ISO 11469:2000 [13] and refers to ISO 1043 - standards, but includes also information about plasticizers and flame retardants that are not covered by the ISO 11469 standard. The implementation of this standard facilitates the identification of the various plastics used in a vehicle, and thus makes it possible to use appropriate recycling and recovering processes in the end-of-life of a vehicle.

6 Existing design guidelines

Dismantling handbooks, Volvo Truck's Corporation

The disposal stage of Volvo trucks are today covered by dismantling handbooks for the various truck-models, for example the dismantling handbooks for Volvo trucks FH series [14]. The handbooks are a practical tool aimed at being used in-end-of life treatment of trucks. The handbooks contain information about the specific materials used in a truck, about the different fluids, their amounts, and guidelines for how they should be treated before the dismantling processes can be found in these guidelines. Furthermore, the various parts and materials of the truck are listed, and illustrated in different colors according to a given legend. Each color represents a specific material; for example the yellow color represents polypropene.

The handbooks are continuously developed, and their contents are modified and complemented by information with respect to knew knowledge.

Design for recycling, DfR – guideline, Volvo Car Corporation

DfR – guidelines [15] of Volvo Car Corporation are intended for designers, and thus may significantly affect the product development with respect to the future recycling and recovery of the vehicle. The guidelines give recommendation on how to form the following components and parts:

- draining systems,
- marking,
- tape and labels,
- binding,
- assembly elements,
- surface conditioning,
- choice of materials,
- glue and welding.

Furthermore, an assessment model is developed to identify the weakness in DfR of the various components. The improvements of the DfR of the assessed components can be effectively directed. The model is exemplified on a number of different parts.

Handbook for designers, Stena Gotthard

The Swedish recycling industry has published guidelines for designers that should facilitate the design with respect to recycling and recovering possibilities [16].The guidelines are formulated for a wide range of materials. The publication, besides the basic principles and guidelines for designers, describes briefly the actual legislation and information about various materials.

7 Summary and Recommendations

This study was aimed at to identify the hazardous substances in component materials for trucks that ought to be avoided from the shredding, and from further recycling and recovery processes related to trucks.

Hazardous substances are substances that according to valid legislation may be expected to lead to injury of human being or damages on the environment. The following hazardous substances and groups of substances are identified to be necessary to phase out [2]:

- CMR substances (substances that cause cancer, are mutagen and disturb the reproduction process);
- PBT substances (persistent, bio-accumulative and toxic substances);

- vPvB substances (very persistent and very bio-accumulative substances);
- mercury (Hg);
- cadmium (Cd);
- lead (Pb).

Metals are the main component materials of a truck (83%), and form consequently also the dominant part of the scrap in its disposal stage. All steel and iron scrap should be free from irrelevant materials [1], such as hazardous chemical substances and products before delivering to a shredder facility. Besides steel and iron (78%), limited amounts of aluminum, copper, bronze, brass, stainless steel, and in the long run also platinum, are used. Moreover, limited amounts of lead can be found in battery for trucks. Nevertheless, batteries are today always dismantled from the truck before shredding, and the use of mercury, cadmium and lead is restricted in production processes of vehicles. Some of the hazardous substances can be found in the alloy steel used in production of trucks. Nickel (Ni) and certain forms of chromium (Cr) that may be used in the alloy steel are classified as substances that cause allergy, and are suspected to be carcinogen. These substances should be handled with a special care, since they may cause problems for the working environment, either in the production of vehicles, or later in the post-treatment processes in the end of life of the trucks.

Currently, the use of plastics as component materials of a truck is 6 %, but their amount is expected to increase. Hazardous substances are often used in production processes of plastics, as additives, softener, pigment, flame-resistant agent, etc. The occurrence of the hazardous substances may be an obstacle in the recycling or recovering processes in the disposal stage of plastics.

To reduce the accumulation and further spread of hazardous substance in the environment, the following recommendations are formulated:

- Hazardous substances should be replaced already in the production processes of trucks, as well as from their component materials, by better environmental alternatives;

- In the design work, tools that facilitate the substitution of hazardous substances should be actively used, for example PRIO guide [6], LIMIT [11], the Volvo's White list [10] etc.;

- Hazardous substances should be excluded from the post-shredder processes of the scrap of trucks; components and materials of a truck that contain hazardous substances should be marked, and specific guidelines should be formulated for their dismantling before shredding;

- A harmonised method for marking of materials containing hazardous substances should be developed.

References

[1] Svenska stålverk och återvinningsindustrier, 2000. Skrotboken (The Scrap Book). Avesta Sheffield AB; Erasteel Kloster AB; Fundia Special Bar AB, Ovako Steel AB, AB Sandvik Steel, SSAB Svenskt Stål AB, Uddeholm Tooling AB, Arvamet AB, Förenade Järnskrot-grossister AB & Co KB, Stena Gotthard Fragmentering AB, Stena Gotthard Återvinning AB.

[2] Proposal of the Swedish Government, 2000/01:65. Non toxic environment.

[3] Kemi (The Swedish Chemical Inspectorate), 1994. KIFS 1994:12.

[4] Klintbom, P. and D. Wahlström. 2001. Screening LCA 2285. Volvo, Report ER-59883 (Company use only).

[5] Sven Ekerot, 2003. Stålets kretslopp (The life cycle of steel). Report D 792, Jernkontoret.

[6] Kemi (The Swedish Chemical Inspectorate), 2004a. PRIO. http://prio.kemi.se (2004-05-14).

[7] Kemi (The Swedish Chemical Inspectorate), 2004b. Restricted database. http://kemi.se/kemi/kategorier/databaser/beransningsdatabas/1028293636.html (2004-05-14).

[8] The Volvo Group, 2003. Chemical substances which must not be used within the Volvo Group. Standard STD 100-0002.

[9] The Volvo Group, 2004. Chemical substances whose use within the Volvo Group shall be limited. Standard STD 100-0003.

[10] The Volvo Group, 2002. Substitutes for hazardous chemical substances. Standard STD 100-0004.

[11] Lidholm P., 2002. LIMIT – Listed Materials Inventory Tool. Volvo, Report ER-59918 (Company use only).

[12] The Volvo Group Standard, 2004. Generic identification and marking of plastics products. STD 103 – 0002.

[13] ISO 11469, 2000. Plastics - Generic identification and marking of plastics products. European Committee for Standardization, Brüssel.

[14} Volvo Parts Corporation, 1998. FH12/16, On the road to increased recycling. (Company use only).

[15] Johannesson, S. 1999. Design for recycling, DfR-Guideline. Volvo Car Corporation (Company use only).

[16] Stena Gotthard. Handbook for designers.

Appendix L

Recycling profitability optimisation using genetic algorithms

- An initial study

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Abstract

In this report a method that make use of genetic algorithms (GAs) for economic optimisation of disassembly in recycling processes is presented. The question posed is what parts to manually disassemble before the rest is sent to shredding to obtain maximum profit. The method is minimalistic in the sense it need only a small amount of input data on the product to be disassembled and it consider selling price decrease due to material mixing. It is capable of generate information on what parts to be disassembled and in what sequence to reach the lowest cost/highest profit. The method is suitable for initial estimations on environmental and economical recyclability costs in e.g. Design for Recycling (DfR). A selected number of parts from a Volvo S60 is used to illustrate the method.

1 Introduction

Nowadays recycling has become a standard procedure for many products. This means that the issue of how to disassemble complex products for recycling need to be considered already in the design phase, which is done in Design for Recycling (DfR). There is a vast literature on methods for evaluating different aspect of recycling, see e.g. Spicer [4] and Kondo [2]. These tools can be used for planning of product retirement, including simple disassembling optimisation. Most of the methods for disassembly sequencing need much data, often based on 3-dimensional analyses of the structure (see e.g. [1]), whereas some are specially designed to provide quick information on economic and some environmental aspects [3]. However, these methods do not consider selling price decrease due to material mixing, which is an important factor for scrapping of e.g. cars. The introduced method is a lightweight disassembly sequencing tool that consider material contamination quality decrease.

2 Method

The method make use of the following information on the product to disassemble:

- Information on precedence in an precedence matrix, A.
- Effort to disassemble a certain part, e.
- Weights for parts, w.
- Compositions for parts, C.

The element $A_{i,j}$ contain an one if the removal of part i before part j is constrained, and zero otherwise. Since most parts are not constrained, the matrix become sparse and hence easy to populate. The disassemble effort is measured using the time to disconnect the part when no other parts are restricting it according to A. It thus not necessary represent the total time to disassemble a given part. The weights for all components are given in a vector (w) and the factors for respective material (C). Dimensions and units for all parameters are given in tab. 1.

Table 1: Parameters. The composition matrix C give the fractions for each material and have no unit.

Name	Description	Value	Unit	Dimension
m	Number of parts	-	-	1x1
n	Number of pure materials	-	-	1x1
A	Precedence matrix	-	-	mxm
C	Composition matrix	-		mxn
M	Weight matrix	$C_{i,j}w_j$	g	mxn
e	Disassembly effort vector	-	min	
p	Price vector pure materials	-	SEK/g	
w	Parts weight vector	-	g	1xm
x	Binary disassemble vector	-	-	mx1
c_{tot}	Total cost	-	SEK	1x1
c_{parts}	Selling price separate parts	-	SEK	1x1
c_{rest}	Selling price connected parts	-	SEK	1x1
c_{dis}	Disassembly cost	-	SEK	1x1
lc	Cost of labour	350/60	SEK/min	1x1

2.1 Economic analysis

The economic analysis aims at finding the net cost for the entire scrapping process, c_{tot}. The scrapping process starts with disassembly of parts which are more valuable when separated from the whole structure. The cost for disassembling is c_{dis}. After selling these parts, which generates the income c_{parts}, the remaining single part is sold for shredding (c_{rest}).

$$
\begin{aligned}
c_{tot} &= c_{parts} + c_{rest} + c_{dis} \\
c_{parts} &= \sum_{m \in x \neq 0} \frac{M(m)p}{\sum_{\forall i}(M(m,i) \neq 0)} \\
c_{rest} &= \frac{\sum_{n \in x=0} M(m)p}{\sum_{n \in x=0, \forall i}(M(n,i) \neq 0)} \\
c_{dis} &= e\,x
\end{aligned} \tag{1}
$$

To account for a lower recycling value for mixed materials, a material contamination factor equals the number of materials is introduced. A mixture of two materials would then only have half the value per kg than a pure material. This affect is accomplished by the term $\sum_{n \in x=0, \forall i}(M(n,i) \neq 0)$ in (1). This way of handling mixed materials is only a very course approximation of the real case. To get a better resemblance, many more materials and the type of mixtures need to be considered. A good model for calculation of economic value of scrapped goods is the VARM model, see Strömberg [5]. By making use of this model, the economic analysis can be made more realistic.

2.2 Feasibility

If row no i in the precedence matrix $A_{i,j}$ only contain zeros, then part no i can be immediately disassembled. If the row contain any ones, the column number j indicate the part needed to be disassembled prior to part no i. By matching wanted with possible parts to disassemble, a set can be found for immediate disassemble. In the precedence matrix, disassembling a part no m can be done by deleting row and column no m. Starting with a binary set of parts to be disassembled (x), the above check for precedence constraints can be done in an iterative way to ensure feasibility. If it is possible to disassemble all wanted parts the binary set is said to be feasible. Concurrently the feasibility algorithm will provide the disassembly sequence.

2.3 Genetic algorithm

The genetic algorithm (GA) used is a standard one, described in Wahde [6] p.32. It make use of binary encoding in the disassemble vector x. An one in x_i means part no i is to be disassembled and an zero that it is to be left for the final shredding.

3 Case study

The case study consists of selected parts of a Volvo S60. The parts are selected from a complete list by the author on the basis of making an interesting initial test case, see tab. 2. Disassembly time and composition is assumed. So is the disassembly constraints and prices for pure materials.

The connections between parts, i.e. how the parts are connected to each other in the car, is viewed in fig 1. It is evident that many of the connections are multiple, creating cyclic chains of connections which are not suitable for tree representations.

The result from the optimisation shows a fast convergence to the expected optimal value (fig 2), in terms of a net income of 541 SEK and the order of disassembly (tab. 5).

Table 2: Selection of parts from a Volvo S60 to be included in the case study. The parts name and their respective weight are real. The time for disassembly and composition are assumed.

Part no	Description	Weight [g]	Disassembly time [min]	Composition
1	Subframe,Kpl	21728	10	1s
2	Engine B5244S	155000	25	0.7a 0.1s 0.1p 0.1o
3	Support beam upper	5470	5	0.9s 0.1r
4	Coolant hose, upper	325	2	1r
5	Cooler, medium size	3210	10	0.95a 0.05p
6	Bonnet	8100	10	0.95s 0.05p
7	Electrical cooling fan	3550	20	0.4s 0.1p 0.5c
8	Battery 520 H5	16000	5	0.1p 0.9l
9	Generator 140A BR14-H F	7080	15	0.5s 0.5c
10	Starter engine 1.4KW+	3200	25	0.5s 0.5c
11	Head beam left	3690	2	0.2p 0.8g
12	Exhaust system P24	19302	2	1s
13	Catalytic converter	7500	5	0.8s 0.2n
14	Transmission oil	1743	5	1o
15	Gearbox M56L Ratio 4.00	46600	10	0.3s 0.7a
16	Drive shaft left side	5296	35	1s
17	Wheel unit l/r 2WD	33680	20	1s
18	Shock absorber front	4390	15	0.4s 0.1p 0.1g 0.4o
19	Wheel ST65-15 195/65	16350	5	0.6g 0.4a
20	Windscreen wiper	2721	15	0.3s 0.2a 0.5c

Table 3: Disassembly constraints. The element $A_{i,j}$ contain an one if the removal of part i before part j is constrained, and zero otherwise. The indicated positions are constrained and all others are free. These constraints are assumed and based on the knowledge of the author.

Row (i)	Column (j)
1	2,5,15
2	3,4
5	3,4,7
10	15
11	8
15	2,8,16
16	17
17	19
18	17
20	6

4 Conclusions and future work

In this report, economic optimisation of disassembly sequencing and extent has been done using GAs. It is shown that the developed method is capable of finding the solution to a test case after no more than 15s of computation time. Since the used algorithm is heuristic, a problem is to verify that the found solution is global and not only a local extreme point. One might, on the other hand, then regard the method as source for improved disassembling rather than a verified global optimiser. In that case the question of verification of uniqueness is less important.

Table 4: Prices for pure material from recycling. All figures are assumed.

Material name	Price [SEK/g]
Steel	0.0020
Plastic	0.0020
Rubber	0.0030
Aluminium	0.0080
Copper	0.0100
Lead	0.0060
Glass	0.0005
Oil	-0.0020
Platinum	0.1200

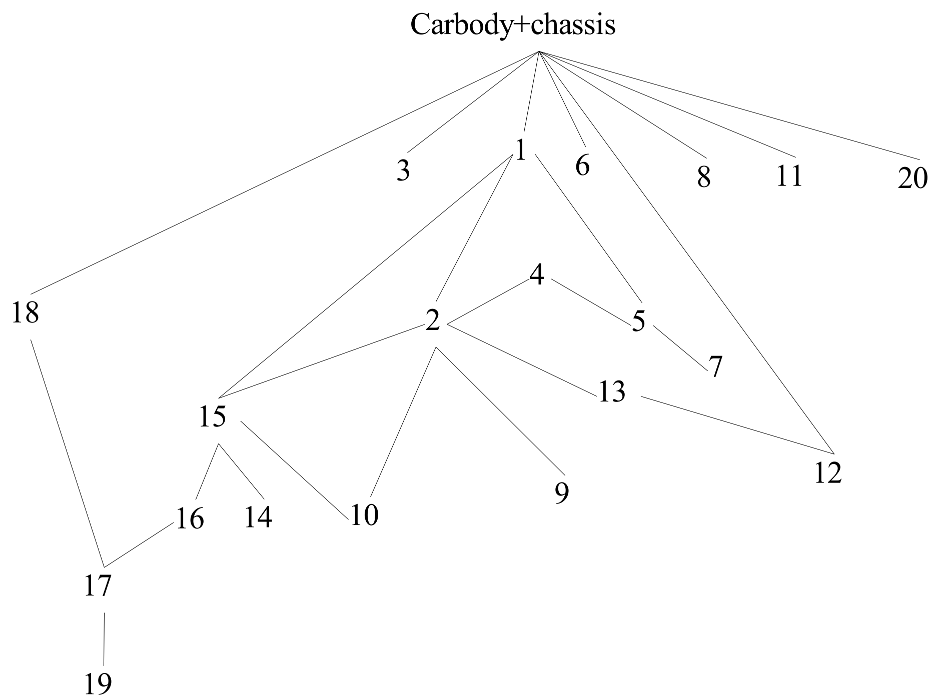

Figure 1: Graph showing structural dependence for the case study object. Indicated parts are connected to each other in the real construction and will possess restrictions by disassembling. The root node is virtual and necessary since not all parts of the car is considered. It now represent all omitted parts.

The method only consider simple economic costs in the present version. Specifically the material contamination factor (see sec. 2.1) need to be improved. One way of doing this is to make use of the VARM model [5]. Another factor to cosider, along with recycling, is reuse. Often the benefits of reuse of a component, if applicable, are higher than for recycling. Also the environmental costs can be included in the optimisation. In general,

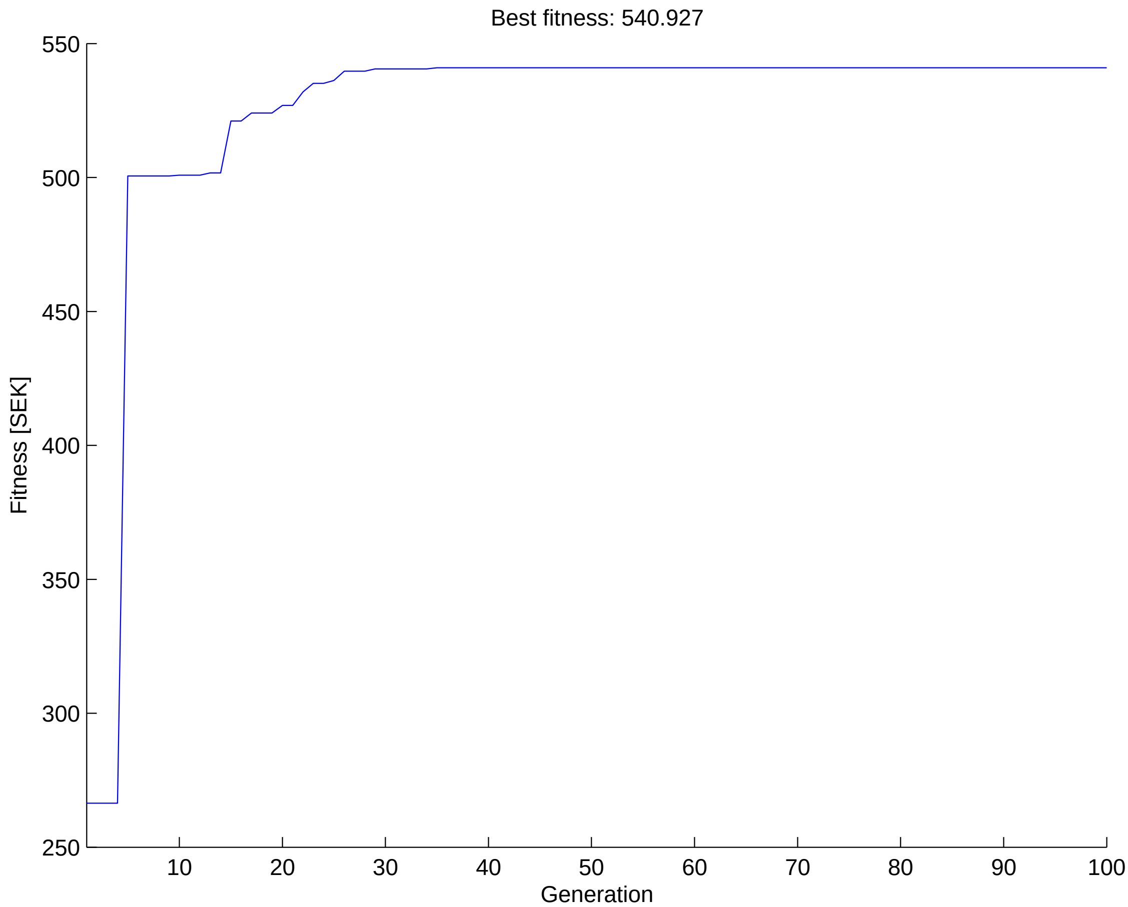

Figure 2: Convergence for the algorithm. Total execution time was around 15s on a 1.5GHz PC.

Table 5: Result of optimization. The indicated is what parts to disassemble before shredding, in what order and the total net income in SEK (best fitness).

Best chromosome:	1 1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 0
Best fitness:	540.9267
Order of disassembly:	
Step 1	Part no 3 4 7 8 9 12 13 19
Step 2	Part no 2 5 11 17
Step 3	Part no 1 16
Step 4	Part no 15

as long as these costs can be quantified, they can be included.

There are also a vast number of alternative ways of stating the optimisation problem, e.g.:

- Adding constraints, such as a specified reuse/recycling rates, which can be given by law. The result is then the most economical way to meet these given rates.

- Changing optimisation variable (x) to e.g. type of material or fastener for some of the parts. In this case the method would find a alternative design for the lowest scrapping cost, i.e. a form of DfR.
- Finding maximal labour cost to make a certain case of disassembly and recycling profitable.

For each of the above cases the developed method can be used with only minor modifications.

5 Acknowledgment

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References

[1] C. Hong and T. Kuo, *A graph-based disassembly sequence planning for eol product recycling*, Int. Electronics Manufacturing Technology Symposium, (1997).

[2] Y. Kondo, K. Miki, K. Hirai, and F. Obata, *A disassembly and recyclable assessment tool for industrial products with complex structure*, Int. J. Env. Conscious Design & Manuf., 8 (2000), pp. 39–45.

[3] K. Seo, J. Park, and D. Jang, *Optimal disassembly sequencing using genetic algorithm considering economic and environmental aspects*, Int. J. Adv. Manuf. Techn., 18 (2001), pp. 371–380.

[4] A. Spicer and M. Wang, *Environmental design industrial template (edit): a software tool for analysis of product retirement*, J. Cleaner Prod., 5 (1997), pp. 193–198.

[5] K. Strömberg, *Valuation of recycled material in lca/dfe*, tech. report, Chalmers Industriteknik (CIT), 2001.

[6] M. Wahde, *An Introduction to Adaptive Algorithms and Intelligent Machines*, CTH, 2004.