

SUPPLIERS WITHIN AN ECOLOGICALLY AWARE AUTOMOTIVE SECTOR

1 Overview on the theme

It is clear that automobiles fulfill other functions besides the one for which they were primarily created: transportation. This has significant consequences in the automobile life cycle; it influences design, use and disposal. In particular, rapid obsolescence of the automobile supported by annual model changes, driven by sophisticated psychological advertising are key drivers for the auto industry.

Over the last 30 years, the automobile has become one of the most important consumer products in industrialized society – second only to the home as the single most expensive purchase by an average family. Yet it is discarded within a relatively short time, typically between nine and thirteen years and its disposal, unless handled correctly, can have a major environmental impact, both in terms of waste products and in the recovery of original materials to conserve resources.

General trends indicate that car ownership is rapidly becoming a routine feature of daily life throughout much of the world, only weakly dependent on such characteristics as age, gender, or income level. In 1997, in the European Union, the number of persons per passenger vehicle varied between 1,7 in Luxemburg and 4,4 in Greece (the average being 2,2), while in the EUA this value was of 2.

The automobile, thus poses a number of challenging questions regarding its sustainability, which go far beyond technical innovation and tangle scientific, environmental, economic, cultural and psychological aspects of the its role in society.

This vision of the automobile sector, clearly shows that from a regulatory point of view, the traditional emphasis on production processes is no longer appropriate, particularly in environmental policy and regulation.

In line with recent European Commission initiatives, an IPP-Integrated Product Policy is to be considered, when the automobile sector is to be considered. IPP addresses the whole life cycle of a product, and seeks to avoid shifting environmental problems from one phase of the product life cycle to another.

The transition to an Integrated Product Policy is a complex process, as emphasized by Berkhout and Smith (1999). A wider network of partnerships between national and international stakeholders must be created, with new rights and responsibilities allocated to public authorities, producers and consumers. The policy process needs to become more transparent, open, interactive and co-operative, placing greater stress on voluntary actions and market instruments, as a complement of rules laid down in legislation.

In particular, in the automobile life cycle, the main actors consist of raw materials producers, components manufacturers, OEM's- Original Equipment Manufacturers, Car owners, repair shops, dismantlers, materials recyclers and shredders, as represented in figure 1.

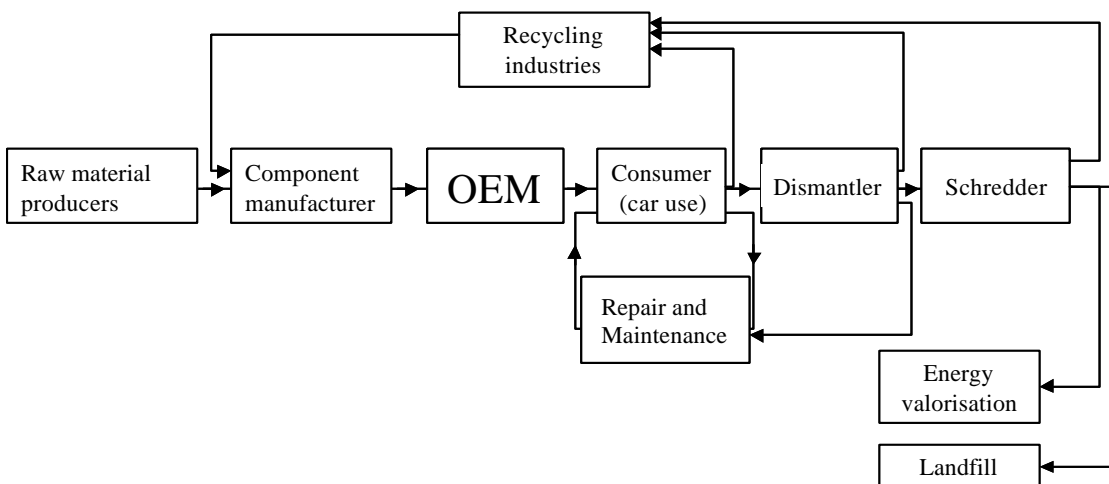


Figure 1 - Automobile life cycle representation

The dismantlers usually get ELV's from the last owner, from car dealers or at auctions from insurance companies. Reusable components with market value and particularly valuable material fractions such as batteries and catalytic converters are removed. The reusable components can be sold to small garages and private owners. The remaining parts and the hulk are sent to shredders.

The shredder reduces the hulk to small pieces, with around 10 cm each. The ferrous fraction is separated from the non-ferrous components using magnetic separation. Air classification allows the separation of the non-ferrous fraction in a light and heavy fraction, characterised by high metallic content. Further separation, in a non-ferrous separator (which may be automatic or manual), makes possible to separate the pieces made of aluminium, copper and zinc, which have a high market demand.

It is clear that the results of a Life Cycle Assessment identify the use phase of the life cycle as a major contributor for the environmental impacts over the complete life cycle, for a significant number of environmental impact categories. Reis I. (1998), made a life cycle assessment of a specific 1.9 l diesel engine vehicle (which travelled 200000 kms during its life) and has evaluated the relative contributions of the production, use, maintenance and recycling/landfill phases, for different environmental categories.

Figure 2 presents the relative contributions of the 4 phases of the life cycle above mentioned, for the following environmental categories: greenhouse effect (global warming), ozone layer depletion, acidification, eutrophication, heavy metals, carcinogenic substances, winter smog, summer smog, pesticides, energy consumption and solid emissions.

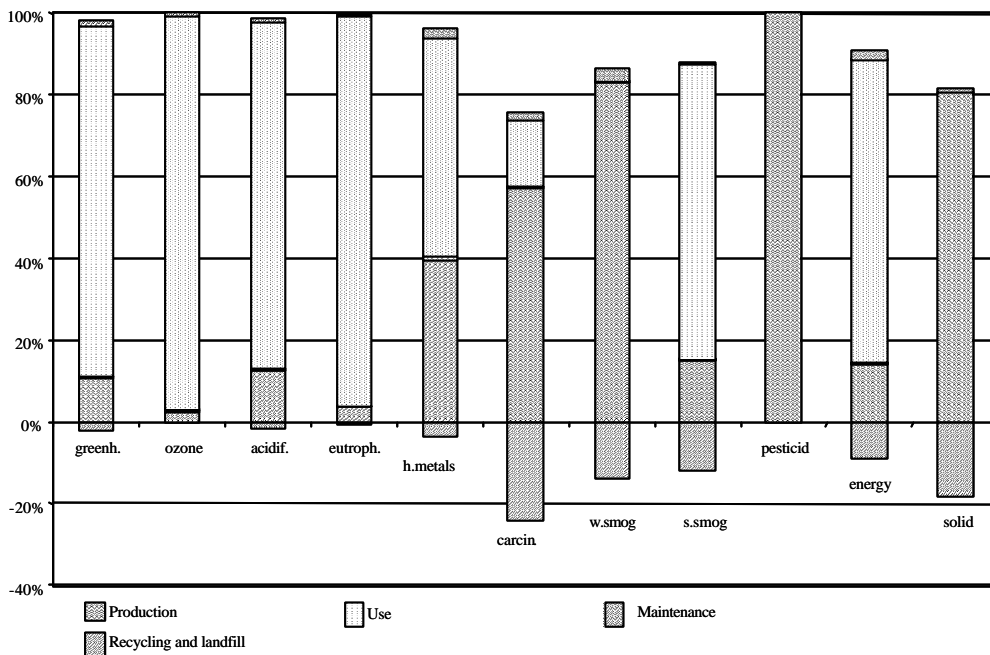


Figure 2- Relative contribution of 4 life cycle phases (production, use, maintenance and recycling/landfill) for different environmental impact categories, for a specific 1.9 l diesel engine vehicle.

This figure shows that greenhouse effect (global warming), ozone layer depletion, acidification, eutrophication, summer smog and energy consumption, are clearly dominated by the fuel consumption and subsequent emissions, during the use phase of the vehicle.

However, the production phase has a major direct impact in the other environmental categories, namely, heavy metals, carcinogenic substances, winter smog, pesticides and solid emissions, and therefore cannot be underestimated.

In addition, the environmental impacts associated with the use phase are essentially dependent on the fuel used, on the type of vehicle use and on the engine performance and car weight. These are product oriented (Automobile)

goals and, as a consequence, controlled by specific regulations, such as the control of pollutant emissions, with minor influence on the supply chain of auto components.

In this study, aimed at analyzing the suppliers within an ecologically aware automotive sector, emphasis is given to the material fluxes associated to the life cycle of the automobile, which is increasingly relevant at European level. In particular, as discussed in the following paragraphs, the key questions to be addressed in this report, are:

1. ELV dismantling and subsequent materials processing
2. Plastics recycling
3. Heavy metals in vehicles
4. Car of the future

The annual waste flux due to end of life vehicles (ELV), of the categories M1 (passengers vehicles comprising no more than eight seats in addition to the driver seat) and N1 (vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes), in the European Union is quantified in around 8 to 9 million tones (in: *Proposal for a Parliament Directive on end of life vehicles in the European Union 8095/1/1999 – C5 - 0180/1999 – 1997/0194(COD)*).

A study performed by two consulting companies for EUROSTAT, indicates, for the period between 1990 and 1994, a flux of ELV, oscillating between 8,200,000 units in 1990 and 9,700,000 units in 1992. There is a certain amount of uncertainty associated with these values, related with the quantification of the ELV fluxes in each country. This is visible, for example, in the fact that the ELV fluxes relative to France, Italy and Portugal, remain constant from 1990 to 1994, EUROSTAT (1999).

Bearing in mind the increase of the circulating park one may reasonably expect the flux of ELV in the European Union, to increase in the near future. An existing

estimate refers an increase of 21 % in the number of ELV, in the European Union, between 1995 and 2010, EEA (1999).

These figures motivated the concern with the ELV processing infrastructure and determined the preparation of EU legislation, under the form of a proposal for a Directive on end of life vehicles, which stipulates minimum recycling rates for automobiles. These targets are to be achieved ensuring that the deliver of the ELV is done at a certified treatment facility and without costs for the last owner.

The ELV dismantling and subsequent materials processing is thus a major concern in this study, and it is to be viewed under current and prospective trends for all the parties involved, namely, OEM's, first tier suppliers, component suppliers, national states and finally, at an EU level.

In fact, for example, it is of little use that vehicle manufacturers produce the most effectively recyclable major consumer item, if end of life vehicle processing activities and materials markets are not developed to promote their integration in economy.

Taking into consideration that the average materials composition of a vehicle, in 1994, could be characterised by: Ferrous metals – 68 %, Non-ferrous metals – 8 %, Plastics – 8 %, Rubber – 4 %, Fluids – 6 %, Glass – 3 % and others – 3 %, and considering that recycling of metals is current practice, one verifies the need (for the prosecution of EU legislation) for a more effective plastics recycling infrastructure. This is particularly important taking into consideration that the plastics content in vehicles has been raising and that so far these materials have been uneconomic to recycle.

Another relevant issue, also mentioned in EU legislation, the heavy metals content, particularly in the automotive shredder residues, that are generally sent to landfill.

The analysis of the global problem of ecologically driven vehicles in a medium-time horizon may not forget the evolving trends in vehicle evolution, which is dynamically adjusted as a function of different factors, including environment. For

example, between 1980 and 1994, plastic, aluminum and high strength steel contents of an average US automobile increased from 6 to 8 %, 4 to 6 % and 5 to 8 %, respectively. The content of conventional steel decreased from 52 to 44 %. Another factor that may affect ELV composition is the change in the propulsion system, which is the case for the hybrid and electric vehicles. In the use phase it is also worth discussing the role of GPS based navigation systems, which may help driving in crowded urban areas with benefits on fuel efficiency. All these topics will be considered under the fourth topic, "*the car of the future*".

The promotion of the closure of material and energy cycles within the automotive life cycle and its interaction with other products cycles, suggests that an adequate conceptual framework for understanding this complex non-structured systems may consist in *Industrial Ecology*.

The idea of industrial Ecology is based upon an analogy with natural ecological systems. In nature, an ecological system operates through a web of connections, in which organisms live and consume each other's residues. In an industrial ecology unit, processes and industries are considered as interacting systems rather than isolated components.

Although the exact meaning of Industrial Ecology is still in debate, this conceptual framework is useful as it may provide the basis to connect different residues into an operating web that minimizes the total amount of industrial material that goes to landfill. Industrial Ecology makes use of several tools, such as life cycle assessment, design for environment, life-cycle cost accounting, cleaner production and systems dynamics models.

In fact, what makes industrial ecology an attractive approach is that it provides a system-based approach, able to analyze complex relationships in a globalising world, and it is integrative, including science, technology and environment, whose concepts are very relevant for an adequate approach to the analysis of suppliers within an ecologically aware automotive sector.

1.1 Main drivers

The main drivers of the technological progress of the automobile industry have been:

- the fulfillment of the consumers increasing expectancies, mainly accessed by the OEM, relating to a number of requirements which may vary over time and space, such as: comfort, esthetics, fuel economy, safety, etc..
- the regulations imposed by public authorities addressing safety and the reduction of the environmental impact associated with the vehicle life cycle (in particular concerning the reduction of: exhaust gases, fuel consumption and non recyclable solid waste).

On the short and medium term, the recycling of end of life vehicles and vehicle maintenance materials and components, in the European Union is being driven by the necessity of reducing landfill waste quantity and hazardousness, namely the heavy metals and PCB contents, while at the same time limiting the quantity of residues being sent to energetic valorization. It should be mentioned that, according with the ECRIS project an automobile consumes about the same quantity of material in its lifetime as the amount used to manufacture it. Trends in vehicle composition, such as the increase in plastic and aluminum contents due to fuel economy and/or the increase in nickel and lithium (materials used in batteries), may have an important effect on the long term.

The necessity for the participation of a large number of players makes the environmental impacts associated to ELV processing a complex problem. ELV recycling must involve public authorities, automobile owners, dismantlers, shredders, insurance companies, repair shops, OEM and component suppliers, recyclers, to name a few.

To reduce the flux of solid waste, the European Union has been developing a proposal for a Directive on end of life vehicles, where recycling targets (per vehicle mass) and minimum requirements for ELV treatment activities are

defined. At the same time the cost of landfill has been increasing (the reclassification of non recyclable automotive residue as hazardous waste would further increase the disposal costs).

These regulations may significantly affect the economics of the existing recycling industrial infrastructure, namely the dismantlers and the shredders. This is a very important recycling industry, both in social and economic terms, which has been existing for some years. For example in Germany there are 65 shredders and 1034 certified dismantlers (according with ARGE-Altauto, the organization responsible for supervising ELV processing, and before the certification process was initiated there were around 3000 to 5000) and in the Netherlands there are 11 shredders and 907 certified dismantlers.

Other aspects which may have a decisive influence on the ELV flux in the European Union and/or introduce significant imbalances between the member states, are the retirement decision (when does a vehicle reach its end of life?) and the export of end of life vehicles.

Automobile owners retire their vehicles for a variety of reasons, such as poor reliability of parts and components, degraded performance, and loss of structural integrity from corrosion or an accident. The decision to retire a vehicle poses a challenging resource optimization problem from environmental and economic perspectives.

According with Wright et al. (1998), the decision to retire a vehicle depends largely on two basic conditions: the ability of the vehicle to meet periodic roadworthiness tests and the financial costs of ensuring that it does so against the costs of acquiring another vehicle. This means the number of vehicles facing retirement is fundamentally linked to the character of the testing regime, which still varies widely around the world – from stringent in developed countries to extremely lax in developing markets. Beyond that, significant differences remain at national level, which influence the flow of vehicles through the recycling process.

In Germany, the annual roadworthiness test is rigorous, and the country exports high numbers of used cars into markets which are less demanding, typically those of eastern and central Europe, but also to more peripheral markets in the EU. In 1994, such sales accounted for about 1 million of the 2.5 million vehicles, which were deemed ELV's in Germany. By exporting these used vehicles, environmental problems associated with car scrap are also exported. The scope for this practice will diminish as other markets develop more rigorous and demanding vehicle testing regimes of their own, Wright et al. (1998).

1.2 Global context

1.2.1 USA

Recycling falls well behind cost considerations in order of importance to US automakers, according to a survey by the Society of Automotive Engineers. While recycling, along with quality issues, was high on the agenda a few years ago, both have declined in stature. The three major automakers can claim to have tackled quality problems, but recycling has slipped away, not because the industry has dealt with the problem, but because whatever public pressure was behind, the issue has disappeared, Wright et al. (1998).

In the beginning of the 90's, automakers were concerned that legislation would force them into the recycling business, following the European example. In addition, the existing auto recycling infrastructure complained about the growing use of plastics. Auto fluff – the material left after recyclers extracted valuable products including steel and non ferrous metals – was expanding as a percentage of the total car, and recyclers worried that the fluff would become more expensive to ship to landfills, Wright et al. (1998).

The plastics industry responded pro-actively to these concerns, making efforts to improve resin labeling of parts, design products for easier disassembly, and set up pilot projects to recycle plastic components. In some cases, the projects have grown into commercial successes, Wright et al. (1998).

In most states, ASR is designated as non-hazardous waste, and it is disposed in Resource Conservation and Recovery Act Subtitle D landfills. In California, ASR does not meet cadmium restrictions; therefore a chemical fixation is required which adds \$20 per ton to the tipping fee. Other states require treatment of ASR to immobilize heavy metals or have imposed other regulations on ASR disposal, Keoleian et al. (1997).

Details of the USA reality can be found in ANNEX I.

1.2.2 Japan

Japanese, South Korean and other Asian carmakers generally see recycling as part of the total environmental compatibility of their vehicles and not as a separate issue. The consensus is that they will follow the legislative lead set by Europe, Wright et al. (1998).

In Japan the number of circulating passenger vehicles has increased from 40,7 million in 1993 to 48,6 million in 1997. In 1997 there were 2,6 inhabitants per passenger vehicle, ACAP (1999).

The issue of recycling of end of life vehicles has also been considered a priority in Japan, where in 1990 a law for the promotion of use of recycled resources, applying in particular to automobile and household appliances industries, was passed. In addition, in October 1996 the Ministry for International Trade and Industry (MITI) drew up a set of quantified targets for the recycling of end of life vehicles (85% by 2002 and 95% by 2015). MITI also called for a drastic reduction of the use of lead in new vehicles.

The Japan Automobile Manufacturing Association (JAMA) set the following recycling targets (see <http://www.nissan.co.jp/INFO/RECYCLE/E/02.html>):

- By the end of 2000: a reduction of lead content in new models (excluding batteries) to one-half of 1996 levels;
- By 2002: new models should be recyclable in more than 90 % (at the design process);
- By the end of 2000: a reduction of lead content in new models (excluding batteries) to one-third of 1996 levels;
- By 2015: new models should be recyclable in more than 95 %, Wright et al. (1998);

According to JAMA statistic, current recycling rate of ELV is 75 % on average (per mass).

Details of the Japanese reality can be found in ANNEX I.

1.2.3 South Korea

In South Korea the number of circulating passenger vehicles has increased from 4,2 million in 1993 to 7,5 million in 1997. In 1997, there were 5,9 inhabitants per passenger vehicle, ACAP (1999). The main manufacturer is Hyundai.

Hyundai says it plans to use recyclability as a significant part in its marketing strategy. 'Hyundai is trying to become a kind of company which customers regard as a car manufacturer producing environmentally-friendly cars'. But Hyundai also believes that "customers need to participate in these recycling efforts by paying for this investment in technology", Wright et al. (1998).

One of the chief areas of concern is whether or not Hyundai is prepared to meet all legislation requirements. Hyundai believes that customers and owners should be responsible for ELV's – making OEM responsible would mean including the collection fee in the price of a new car which would directly affect sales. But manufacturers and importers need to set up recycling programs with other manufacturers in certain markets as long as the relationship can reduce the cost, or make recycling more effective. Joint recycling programs could be much better in some areas, Wright et al. (1998).

South Korea has the youngest car fleet in the world with just 0,35 % of vehicles more than 10 years old (against a world average of around 36 %) and 55 % being under 3 years old. According with Wright et al. (1998) this may in part explain why South Korea has a more relaxed view on ELV recycling.

1.2.4 The European vision

Over the last 30 years, the car has become one of the most important consumer products in industrialized society – second only to the home as the single most expensive purchase by an average family. Yet it is discarded within a relatively short time, typically between nine and 13 years and its disposal, unless handled correctly, can have a major environmental impact, both in terms of waste products and in the recovery of original materials to conserve resources.

In the EU the number of circulating passenger vehicles increased from 102,6 million in 1980 to 167 million in 1997 (in this year there were 2,2 inhabitants per vehicle), ACAP (1999) and Eurostat (1998).

The annual waste flux due to end of life vehicles (ELV), of the categories M1 (passengers vehicles comprising no more than eight seats in addition to the driver seat) and N1 (vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes), in the European Union is quantified in around 8 to 9 million tones (in *Proposal for a Parliament Directive on end of life vehicles in the European Union 8095/1/1999 – C5 - 0180/1999 – 1997/0194(COD)*).

This aspect motivated the concern with the ELV processing infrastructure and drove to the preparation of EU legislation, at the present under the form of a proposal for a Directive on end of life vehicles, which stipulates the following targets:

- 18 months after its ratification: new vehicles commercialized after this date can not contain lead, mercury, cadmium or hexavalent chromium, with the exception of some cases referred in the annex of the Proposal for an European Directive.
- Until 01/01/2006 – valorization of 85 % (recycling 80 %) for vehicles produced after 1980, per mass
- valorization of 75 % (recycling 70 %) for vehicles produced before 1980, per mass
- Until 01/01/2015 – valorization of 85 % (recycling 85 %), per mass

These targets are to be achieved ensuring that the deliver of the ELV is done at a certified treatment facility and without costs for the last owner.

(in *Proposal for a Parliament Directive on end of life vehicles in the European Union 8095/1/1999 – C5 - 0180/1999 – 1997/0194(COD)*).

Estimates presented by a study from two consulting companies for EUROSTAT, indicate, for the period between 1990 and 1994, fluxes of ELV in the EU, oscillating between 8,200,000 units in 1990 and 9,700,000 units in 1992. There is a certain amount of uncertainty associated with these values, related with the quantification of the ELV fluxes in each country.

More conservative estimates are provided by a report from MAVEL commissioned by the Association of Plastics Manufacturers in Europe which indicates the following values for the ELV flux in the European Union: 9,3 million in 1990, 6,3 million in 1994, 8 million in 2000 and 9,5 million in 2010, MAVEL (1997).

This report also states that:

- The number of ELV will continue to grow from 1996 to 2015
- The number of ELV can vary significantly from one year to another
- Significant variations from region to region within the same country can be observed
- Previously the number of ELV has very often been overestimated (because exports of second hand cars to third countries were underestimated and official car fleet figures have not been corrected)
- The political changes in Central Eastern Europe have created a very special situation in Germany

A description of different European initiatives aimed at enhancing ELV's processing is provided in ANNEX I.

2 ELV dismantling and subsequent materials processing

2.1 The proposal for a Directive on end of life vehicles

The main goals of the proposal for a council directive have already been discussed and are depicted in figure 3 below. This figure shows the different actors involved in the ELV processing and quantifies the main re-use and recovery targets on 80% by weight per vehicle by 2006 and 85% by 2015 and for the re-use/recovery of ELVs, they are 85% by weight per vehicle by 2006 and 95% by 2015.

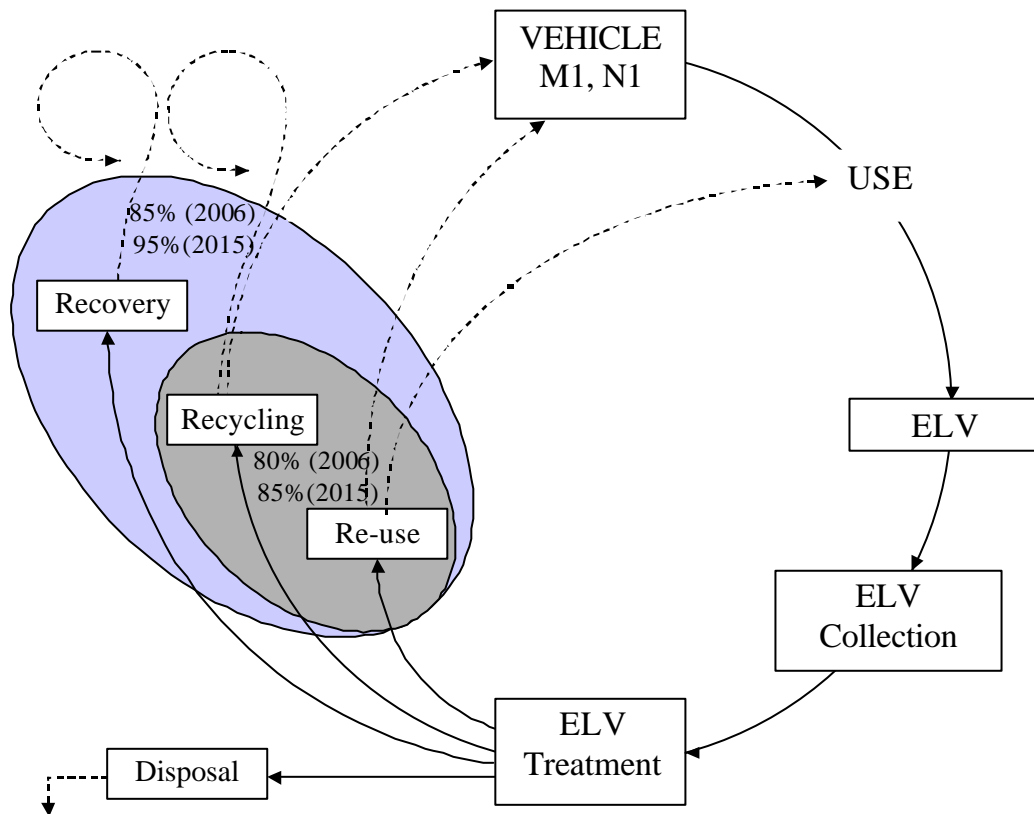


Figure 3- Main goals of the proposal for a council directive

In addition, the directive establishes minimum requirements for the ELV treatment, as illustrated in figure 4. The fulfilment of these requirements are essential to promote a market of recyclable materials, but further and effective arguments and regulatory actions have to be put in the market for it to be able to accelerate its maturity and its ability to control the material flows.

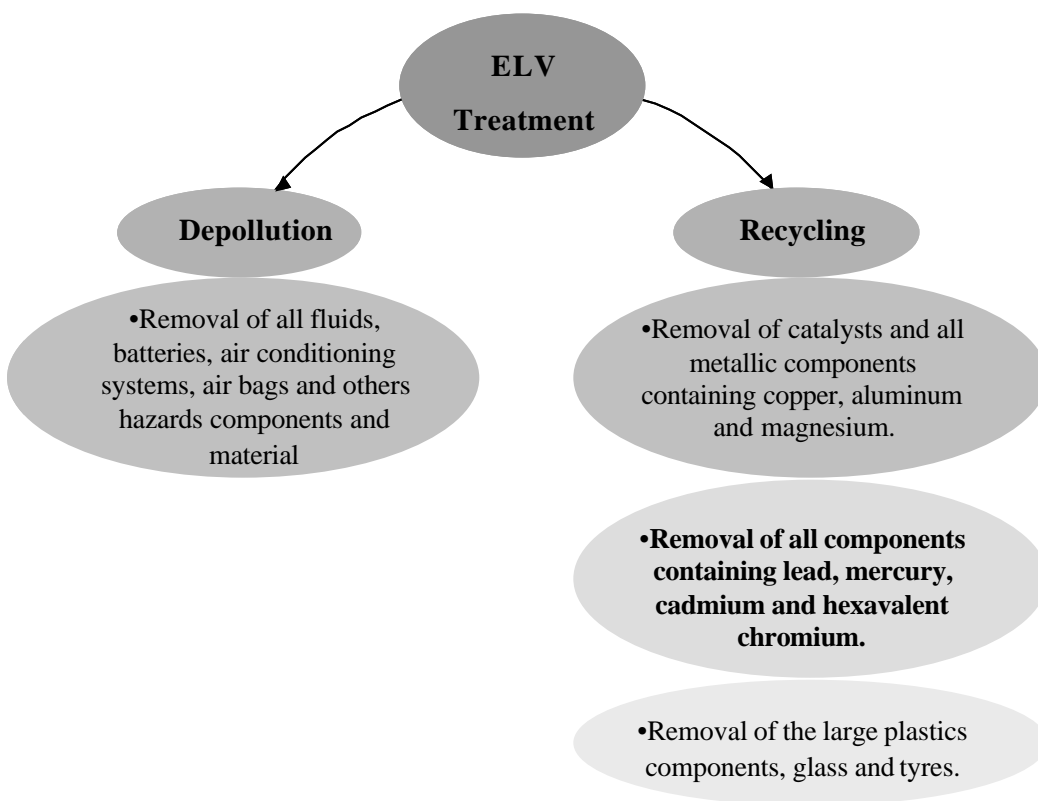


Figure 4 - minimum requirements for the ELV treatment

The design of regulatory actions requires detailed knowledge of the main actors involved in the processing of ELV and their technologies, and this is discussed in the next section.

2.2 ELV processing

The average materials composition of vehicle, in 1994, can be illustrated as follows: Ferrous metals – 68 %, Non-ferrous metals – 8 %, Plastics – 8 %, Rubber – 4 %, Fluids – 6 %, Glass – 3 % and others – 3 %. Bearing in mind the existent solutions for the recycling of: metals, fluids, glass and rubber, one verifies the need (for the prosecution of EU objectives) for a more effective plastics recycling.

The automotive industry increasingly accepts recycling as an imperative and it has become integral part of the process of designing, building and ultimately dismantling and disposing of cars and their parts.

However, this enormous productive sector realises that there is little to be gained by creating systems, which will, within one decade, make the vast majority of a car recyclable, unless that process is economically viable.

This involves a huge effort on developing infrastructures and procedures that have to be guided by actions from the European Commission, like the latest proposed end-of-life vehicles (ELV) directive, that provide an insight into the “extended product responsibility” principle, although its target group was extended to include those who dismantle and reprocess the ELVs.

This section is intended to analyse available ELV processing technologies and their subsequent materials flows and, on the light of a brief discussion on the proposed directive to provide elements for further development of an integrated and effective regulatory strategy which take into consideration the different actors along the vehicle life cycle.

The continuous increase of registration of new vehicles in the European countries and thus the increase of the number of ELV's to be processed, and new developments in the design of automobiles, for example increased plastics contents, requires new strategies in the field of car recycling, in order to process all ELV's in an environment-friendly manner in the future.

According to the recycling priorities, the aims are based on the necessity of a society with less waste production, giving emphasis to the prevention of waste. This aim has to do with the quantity, the way of use and the time of use of the products and to the recycling of non-avoidable waste. After dismantling, the reuse, recycling and recovery of dismantled products is made possible.

In principle, there are two main strategies to reach these aims and especially to solve the problems caused by the light fraction of the automotive shredder residue (ASR), currently going to landfill:

1. Upgrading the technologies available for processing the light and heavy fraction of the automotive shredder residue, by developing separation technologies and finding recycling possibilities for the products gained from the separation (this is currently done by the German ARGE-Altauto)
2. Dismantling ELV's, which allows a genuine identification of the car parts or materials used in the vehicles (this is currently done by the Dutch Auto Recycling Nederland B.V.; parts with an economical value, batteries and tyres are also dismantled and liquids are removed in Germany)

According to the recycling priorities, 2) has to have a higher assessment because it is focused on material recycling. Strategy 1) is focused on incineration with energy recovery for the plastics and rubbers, which is currently more economically efficient than the second strategy. A genuine separation of the plastics from the light fraction of the ASR is currently not possible and it is also very unlikely to happen in the future.

Normally, both strategies should be followed, in order to meet the recovery aims given by the European legislation for the year 2015 (95 % recovery and 85 % recycling).

The dismantling and removal of the liquids from ELV's creates the conditions to identify with precision the different materials to separate the materials and hazardous components originating from ELV's and thus allows:

- the material recycling and the creation of new life cycles for each material, or the use for thermal recovery of the materials
- the treatment, disposal, recycling and recovery of the liquids and hazardous waste originating from ELV's

Additionally to the increase of the recycling quota, there is a possibility of an increase in parts reuse, due to the systematic dismantling of the ELV's. With appropriate means of control and repair, which are made after dismantling, there is a gain of used parts, which can be reused subsequently (based on Härdtle et al, Altauverwertung, 1994).

The strategy for dismantling cars more effective requires an identification of the plastic parts in the car industry. Plastic parts have to be easily identifiable and thus they can be recycled directly, and generally this identification is currently already made (VDA-Richtlinie) for all plastic parts above the weight of 100 g.

The total amount of the waste emitted from ELV's after shredding (about 25 mass-% of the input) could be reduced due to dismantling to approximately 13,5 mass-% of the emitted waste (for example: Opel Corsa, 1.0, 12 V Eco, 3 doors, 55 HP, empty weight 930 kg; according to IDIS-Software (version 1.0.5) the weight of material dismantled could reach around 108 kg, which corresponds to 11,6 % of the weight and thus 46 % of the currently emitted waste). Additionally, the disposal of the light fraction of the ASR to landfill would be easier because of the completely drained off car wrecks and the removed batteries and thus less hazardous materials inside.

The dismantling technology will not substitute the shredder technologies, but will be and already is a well-established complementary technology in order to have more material available for recycling. The shredder technologies will not be substituted because of the requirements of the steel industry in what concerns steel scrap (a specific bulk weight of more than 1,1 t/ m³ and a purity of scrap contents of more than 98 %). The dismantling is a part of the whole car recycling process.

Another advantage of previous dismantling is that the requirement of energy for the fragmentation is less than the requirement of energy for the fragmentation without previous dismantling.

ELV's normally run through two main branches of industry: dismantling companies and shredder facilities. Only in some cases the ELV's run directly through shredder facilities and this normally happens when the car is already in a poor condition and when the last owner hands it over directly to the shredder facility. Competitors of shredder facilities are scrap shears, in which car wrecks are cut in parts, or presses, in which car wrecks are compacted into cubes. After compaction or cut into pieces the wrecks are delivered to the steel industry. It is estimated that about 15 % of the processed cars are processed with scrap shears and presses (source: Härdtle, G. et al, *Altautoverwertung* 1994). The remaining 85 % are processed by the shredder facilities. Normally, only the shredder facilities can guarantee the requirements of the steel industry, a specific bulk weight of more than 1,1 t/m³ and a purity of scrap contents of more than 98 %.

Details of dismantling technologies can be found in Annex II, and details of shredder operations are described in Annex III.

2.3 Perspectives from different actors

2.3.1 OEM

Design for recycling is always considered the fundamental solution for most recycling problems. For automobile recycling, design for recycling means that the material concerns must be addressed early in design and product development. The industry should be fully aware of future recycling demands

and any possible legislated material bans and incorporates the conception of recyclability into product design and manufacturing processes.

The critical works of design for recycling include reducing the diversity of materials employed in the automobile, applying lower amounts of non-recyclable materials, clearly labelling different material species in all components, and adopting more dismantler friendly techniques in automobile manufacturing so that used parts and secondary materials can be easily identified and recovered by dismantlers and shredders. Additionally, automakers should establish their partnership with material suppliers, dismantlers, and shredders so that all the technological and economic factors that affect recyclability can be taken into account. Most importantly, manufacturers should enhance the importance of recycling-related concepts among their design and production considerations.

Suppliers, which are involved in the creation of a large percentage of a vehicle's added value, must join forces with the OEMs to share responsibility for responding to new ELV recycling issues and obtaining type approval for new models.

2.3.2 First tier suppliers

2.3.3 Component suppliers

2.3.4 National states

2.3.4.1 Creation of a Fund

A fund should be created in order to pay premiums for additional dismantling, for the transport of the dismantled materials and for the recovery. The form of administration should be carefully analysed in order to prevent high system costs.

Financing ELV processing activities

- Dismantling

Dismantling premiums should be paid for the dismantling of plastic parts, rubbers and the glazing, in order to be able to promote the dismantle of an amount of about 100 kg. If these 100 kg are dismantled and recycled from an ELV, the set up legislation for the year 2005 with 85 % by weight recovery and re-use could already be met (average weight of the vehicle 1000 kg; 75 % by weight metal contents, therefore 100 kg correspond to 10 % by weight)

No premiums should be paid for the removal of the liquids and for the removal of the batteries, because this is an obligation for the dismantler.

- Transportation

The transport of the plastic parts, rubbers and the glazing should be paid. A system as in the Netherlands, with an organised transport and with special containers, could be implemented. Transport companies should be contracted for the collection and the delivery of materials to the processing companies. The transport of liquids and batteries could be paid, but taking into consideration that the removal of liquids and batteries is an obligation of the dismantlers. Therefore, contracts between the fund administration and the dismantlers should be made. Such a transport and delivery of materials to processing companies has the great advantage that it is accompanied by the transparency of the mass flows. Another advantage is that high quantities normally guaranty lower prices for the processing of the materials. A disadvantage could be that recycling companies, which are only a few, could raise the prices because the fund administration has to find a receiver of their products.

- **Recovery**

The main principle while making the recovery of the materials is that it has to be done accompanied by low costs. The recovery of liquids and the recycling of batteries is very important because of its hazardous character. The payment for the recovery of liquids should be made by the dismantlers because of their obligation of removal (the batteries are exchangeable for money because of the value of the lead). In what concerns the recovery of the plastics and the rubbers, it has to be cheap, the incineration with energy recovery or the co-incineration could be more adequate as the recycling. The recycling of battery housings, for example, could be done. The glass could also be recycled or used in the road construction. A last possibility could be landfill tipping.

2.3.4.2 Highlights of the regulatory system in the Netherlands

In the Netherlands all vehicles have to be registered at the national car register RDW (Rijksdienst voor het Wegverkeer) and the owners have to pay an ownership tax. The vehicle can be deleted from the national register, if the vehicle is given to a dismantler or if the vehicle is exported abroad. The deletion can only be made, if the dismantler deletes the vehicle from the register or if the owner obtains the *Certificate of Destruction*. Dismantlers are entitled to validate the deletion, if they are connected to the ORAD (Online-Registratie Autodemontage) online registration in car dismantling. According to the information obtained, the dismantlers have to pay 30 Guilders per month to participate at the online registration. In 1995, 415,000 passenger cars and 57,000 commercial vehicles were deleted, of which, according to the data given by CBS, 81,000 vehicles were exported. These deleted 472,000 vehicles correspond to about 7 % of the total park. In the Netherlands, the Automobile Shredder Residue is considered as hazardous waste.

2.3.4.3 Highlights of the regulatory system in Germany

In Germany all vehicles have to be registered at the national car register (Kraftfahrt-Bundesamt) in Flensburg and the owners have to pay an annual ownership tax. The tax depends on the pollutant character of the vehicle. The tax is for Euro-III or D3/Euro-IV or D4/3-litre vehicles 10 DM/ 100 cm³/ year for a petrol engine and 27 DM/ 100 cm³/ year for a diesel engine.

This means, for instance, that for a vehicle with a petrol engine with a cylinder capacity of 1000 cm³ (for example Polo Fox 1.0i) the owner has to pay 100 DM/ year. For a similar vehicle with a diesel engine with a cylinder capacity of 1700 cm³ (for example Polo Fox 1.7 SDi), the owner has to pay 459 DM/ year.

The tax for Euro-II vehicles is 12 DM/ 100 cm³/ year for a petrol engine and 29 DM/ 100 cm³/ year for a diesel engine. The tax for Euro-I vehicles is 13.20 DM/ 100 cm³/ year for a petrol engine and 37.10 DM/ 100 cm³/ year for a diesel engine.

The Euro classifications are based on the EU exhaust gas legislation. The Euro-II exhaust gas legislation came into force in 1996. Euro-III and Euro-IV are planned for the years 2000 and 2005.

For other vehicles, which cannot fulfil the exhaust gas legislation there are three other classifications with taxes up to 41.60 DM/ 100 cm³/ year for a petrol engine and 65.50 DM/ 100 cm³/ year for a diesel engine. For a vehicle, which cannot fulfil the exhaust gas legislation, with petrol engine with a cylinder capacity of 2000 cm³ the owner has to pay 832 DM/ year, which is a considerable amount.

The tax classification should be an incentive for the purchase of vehicles with less emission. Additionally to the tax rates there are supplementary exhaust gas limits D3 and D4, which allow limited exemption from taxes until the year 2005. D3 vehicles can have an exemption until 250 DM in the case of the petrol engine and until 500 DM in the case of the diesel engine. D 4 vehicles can have an exemption until 600 DM in the case of the petrol engine and until 1,200 DM in the case of the diesel engine.

There are also limited exemptions for vehicles until 2005, which emit less than 90 g CO₂/ km (1,000 DM; the so-called 3-litre-car) and which emit less than 120 g CO₂/ km (500 DM; the so-called 5-litre-car), (source: The Association of Motor Vehicles Importers VDIK). According to the information obtained, until now, only the Volkswagen Lupo 3L is accepted as a 3-litre-car and fulfils the D4 exhaust gas limits and is therefore until the end of 2005 exempted from the tax.

2.3.5 European policies

To upgrade car recycling and to implement an environmental-friendly car recycling system, a lot of efforts will be needed by all players involved. All players involved have to do one's bit to upgrade the situation.

2.3.5.1 Policy to increase public Awareness

Everybody involved in the topic should be aware of the importance of the upgrade of the situation in car recycling. This includes all citizens, the authorities, car owners, dismantler, operators of the shredder, operators of other plants for further recovery, car manufacturers, the police and others. Everybody involved should take part of the system. The authorities, the involved organisations (motor vehicle traders and others) as well as the car manufacturers, which have to take over their producer responsibility, should also financially contribute to all activities for the creation of a system and the upgrade of the situation. Such contribution show that they are also interested in the upgrading of the system and the car owners do not exclusively carry the financial burden.

2.3.5.2 Effective working National Car Register

The correct determination of the number of circulating vehicles as well as the number of the vehicles deleted from the car register per year is essential for further monitoring made in the field of car recycling. The determination of the average weight per ELV, for instance, is made by calculating the average weight

of the deleted vehicles per year. The average weight per ELV is needed for the further calculation of the recycling quota.

An effective working National Car Register should be created by the implementation of an Annual Ownership Tax. Based on the experiences, already described in the first chapter, in Germany, the Netherlands (Annual Ownership Tax) and in Portugal (no Annual Ownership Tax), such a measure is essential for the determination of the correct numbers of circulating vehicles. Such an ownership tax should be linked to the *Certificate of Destruction* of the vehicle. Thus, there is an incentive for the hand over of the vehicle to a certified dismantler. The deletion from the register can only be made if the owner of the vehicle presents the *Certificate of Destruction* to the authority. The annual ownership tax could be implemented as in Germany, based on the European exhaust gas legislation, in order to reduce exhaust gas emissions. A side effect of this form of ownership tax, depending on the exhaust gases emitted, is the renewal of the fleet of vehicles. As a side note, it must be said here that temporary campaigns to promote disposal of the ELV's, are to be considered with extreme precaution, as when temporary premiums are paid for the disposal of the vehicles (already done in Italy), during these periods many vehicles are taken from the market and processed, and afterwards less material is available for dismantling yards and shredder facilities, which causes market disruptions.

The implementation of an annual ownership tax has therefore the following advantages:

- determination of the correct number of circulating vehicles
- incentive for the hand over of the vehicle to a certified dismantler to get a *Certificate of Disposal*
- renewal of the fleet of vehicles
- reduction of exhaust gas emissions

The disadvantage of the implementation of such a tax is that it is normally unpopular for the politicians to implement any new tax.

A compromise could be therefore the implementation of such a tax accompanied by the reduction of the automobile tax. An information campaign should be therefore made to clarify such implementation. Additionally, a consensus should be found among the political parties to prevent any polemics surrounding this important topic.

2.3.5.3 Implementation of the demanded National Legislation by the Commission of the European Communities

The Commission of the European Communities will impose the adoption of the European directive on ELVs to national legislation. However, at a national level, detailed descriptions should be made according to the requirements of the dismantling yards and the plants for further recovery. A *Declaration of Localization* (Verbleibserklärung), which exists in Germany and causes great problems with exported cars, instead of obtaining the *Certificate of Destruction*, should only be allowed in special cases (collection cars, for example). The export of ELV's should be carefully accompanied with by monitoring its destination, namely to ensure that it is processed by certified dismantlers and to certified plants for further recovery in other Member States.

3 Plastics Recycling

The use of plastics has been increasing during the last decades due to several factors, as its cost and the ability to be easily moulded in complex shapes, but environmental issues are a major driver too. Reducing CO₂ through light weighting is an area in which plastics will play a major role if recycling targets at end of life are achieved.

This duality between recycling and Reducing CO₂ through light weighting is the main the main question to be solved to extend the use of plastics in the automotive industry, as technically, plastic components are becoming far more versatile and designers are finding ever more creative ways in which to use them. The use of plastic replaces two or three times the equivalent mass of a conventional material. This is as much important as it is known that a reduction in 10% of a vehicle's weight may result in a fuel consumption reduction of 7%.

As a consequence, plastics are set to play a major part in the future of the automotive industry. Figures published in the last quarter of 1999 by the Association of Plastics Manufacturers of Europe (APME) indicated that 1.7 million tonnes of plastic material was put to automotive use in 1997. During the last 20 years, the volume of plastic used by European automotive manufacturers has increased by more than one million tonnes. That is equivalent to 30kg per car, or an increase from 70kg to 100kg.

Recycling will continue to have a bearing on the choice of materials. In a typical modern car over 75% of the vehicle weight is recyclable. 34% of vehicles being scrapped in 1999 were of a 1970s design; only 31 % of end-of-life vehicles in 2005 will have been designed in the 1990s, with the balance from the 1970s and 1980s. The use of plastics continues to rise, and around 8% of vehicle weight is made up of plastic components.

Estimates produced by MAVEL show that the plastics contained in shredded cars, in Europe, exceed an annual amount of 500,000 ton, and that by 2015, this amount will reach almost 1,000,000 ton.

However, it is clear that dismantling of car parts can only be considered if:

- The treatment of plastics is more ecological than when plastics are just left in the car and become part of ASR
- The dismantling processes are financially sustainable.

As major requirements for dismantling to be financially sustainable, the following can be pointed out:

- Parts to be dismantled should be generally big and accessible;
- The materials reclaimed from these parts must be present in a sufficiently large number and their quality must be good enough to treat them efficiently;
- The ways of plastic recovery must be adjusted to the local conditions (country and region). Only a few regions represent a solid quantity;
- The availability of plastics to be recycled must be regular, in time;
- De-proliferation of materials should be avoided;
- Materials identification codes should be provided;
- Design for disassembly, should be promoted;
- Materials recycling technology development should be incentivated;
- Market acceptance of recyclate should be promoted (OEM quality demands);

Several constraints to the accomplishment of these principle can be mentioned, as the trade of ELV's within EU and to abroad, which can have consequences on the regularity of the flows into each country market, plastics coding, consumption and waste availability, recycling limits, and alternatives to recycling. These topics are briefly discussed in the following paragraphs.

ELV's trade

Based on a study carried out by Mavel, it is revealed that around 20% of old cars and trucks (based on annual registration) are exported outside of Europe (Central and Eastern Europe and Africa), to be used as second hand vehicles. Those exported vehicles are not scrapped in Europe.

Plastics coding

It is widely anticipated that plastics recycling is ready for volume production with the advancement in the use of internationally standardised code letters on plastic parts. In new models, emphasis is placed on design for recycling and the use of identification codes is one of the vital standard features.

The current text of Art. 8 of the Commission's Proposal for a Directive on End of Life Vehicles (COM97-358 final) requires Member State a to ensure that car manufacturers and their suppliers use common component and material coding standards for those components and materials which are suitable for re-use and recovery. In this proposal the European Commission commits itself at promoting the preparation of appropriate European standards relating to the identification and codification of components and materials (included plastics).

Consumption and waste availability

According to a research undertaken by TNO Sofres Consulting to APME, an end of life vehicle scrapped (shredded) in 1995 corresponds to a car that was registered 10 to 15 years ago. Therefore the plastic content is not 100kg, but rather comprised between 60 to 70kg.

The plastic content of an average European car manufactured in the 1990's is:

- PP battery 1 %
- PP bumper 10% (25% PP totally)

- PP sides parts 13%
- PU seat foam 10% (15% PU totally)
- HDPE fuel tank 8%
- Dashboard mixed products 14%
- Others 44%

making around 100 kg per car.

As far as PP waste is concerned, waste quantities are estimated at 280 ktonnes in 1995, of which 60 ktonnes are used PP battery casing (21 % of total PP waste). In addition, PP parts (for instance bumpers) were not often used 10 to 15 years ago.

In 1997, only 10% of the dismantled cars are equipped with HDPE tanks and 90% with steel tanks (corresponding to cars manufactured in the 1980's), whereas the market share of HDPE tanks is currently 70% HDPE against 30% for steel. In 2006, the share of HDPE tanks in end-of-life vehicles will increase compared to steel tanks.

Two kinds of plastic waste arising from the automotive sector can be considered:

- short life span plastic parts: batteries, damaged bumpers, ... Battery manufacturers collect most of the used batteries (around 90%) and recover the lead content. The battery is first dismantled and then shredded. Lead is extracted and recovered.
- plastic parts having the same life span as the vehicle: interior covering, tanks,

90% to 95% of post user automotive PP waste handled by plastic recycler comes from PP battery casings and only 5% to 10% from PP damaged bumpers, the latter being collected through the commercial network of car manufacturers and, in very small quantities (less than 1 ktonnes) from dismantling centres.

Most of the seats in new cars are made of PU foams. Some recyclers (3 or 4) in Europe recycle PU foams, dismantled by cars manufacturers. Around 6 ktonnes were mechanically recycled in 1995.

Current recycling limits

TNO Sofres Consulting consider that from the point of view of cars manufacturers, dismantling and recycling can only be feasible (to a certain extent) for larger plastic parts. The economical feasibility of plastic recycling should not be analysed for plastic parts only, but within a global evaluation including dismantling and reselling of spare parts.

- Plastic parts are:
- PP bumpers;
- PP battery casings;
- PU seats;
- HDPE tanks;
- dashboards;
- PMMA lights;
- wheel disks and PA ducts.

After being dismantled, PP bumpers may contain other materials: iron screws, paint coatings, PE hit absorbers, ... All these materials have to be removed in order to obtain pure recycled PP and meet outlet requirements. The main problem is to remove the paint during the recycling process, which is technically and economically difficult.

The granulation of used HDPE fuel tanks is problematic because of the fuel absorption and of the fluoride content (permeable to gas). The maximum content of recycled resin into a HDPE tank is 40%. In 1997, no HDPE tanks are made of recycled resin.

Recycling and its alternatives

There are likely to be three possibilities: re-use on newly-produced vehicles and those still on the road; reprocessing into plastic raw material and energy valorisation, including turning plastic back into petroleum.

Re-use on new models seems unlikely as designs and specifications change so rapidly and are likely to speed up further. The main outlet, therefore, would be re-use as replacement parts on the models from which they came, inevitably a shrinking market.

Reprocessing would depend on two major assumptions, as already discussed. First, that the resulting raw material could be produced at less cost than that from the basic feedstock. Second, that there would be a market for this material irrespective of the production route.

Against these, conversion of plastics into energy warrants serious study. Incineration with thermal valorisation is foreseen and limited in the ELV directive proposal. In addition, it should be possible to turn plastic back into petroleum. Chemical recycling consisting of depolymerising polymers to return to their original substance already exists. Unfortunately, the experimental processes available are too costly for the relatively meagre results they achieve.

As a conclusion, it seems that alternatives to recycling are limited and therefore, the emphasis should be put on analysing current barriers to recycling and to provide effective solutions to improve its efficiency from automotive design to parts collection and processing.

3.1 *Perspectives from different actors*

3.1.1 OEM

3.1.2 First tier suppliers

3.1.3 Component suppliers

3.1.4 National states

3.1.5 European policies

The directive mentions the PVC saying that the EU commission is at the present, analysing the environmental impact due to the PVC.

4 Heavy metals

Another relevant issue, also mentioned in EU legislation, is the heavy metals content in the automotive shredder residues, that are sent to landfill, which may have significant environmental impacts, namely the pollution of surface and ground water.

Pollution from landfills can go on for centuries, as can be seen in the report of the Environmental European Agency (1999), which refers the following estimated times, needed before the leachate can be released without risk to groundwater resources (considering a rate of leachate production of 400 mm/annuum):

- 300 years for hazardous waste landfill;
- 150 years for municipal solid waste landfill;

Experiments conducted in Switzerland revealed the following contents of heavy metals, Brunner et al. (1999):

- in ASR resulting only from automobiles: up to 9047 mg/kg of lead, 40 mg/kg of cadmium, 1 mg/kg of mercury, 383 mg/kg of tin and 6931 mg/kg of zinc.
- in ASR resulting from mixed scrap: up to 7468 mg/kg of lead, 72 mg/kg of cadmium, 6 mg/kg of mercury, 1376 mg/kg of tin and 25989 mg/kg of zinc

Analysis of ASR from a German shredder, performed for a study commissioned by the Association of Plastics Manufacturers in Europe and the American Plastics Council, produced the values indicated in table 1.

Heavy metal	Coarse ASR	ASR fines
Cadmium	51	60
Mercury	2.8	7
Antimony	410	147
Arsenic	46	47
Lead	2582	8425
Chromium (total)	321	445
Cobalt	45	62
Copper	17612	7780
Manganese	569	1378
Nickel	523	332
Vanadium	22	36
Tin	192	380
Zinc	10827	33300

Table 1 - ASR characteristics, Mark et al. (1998) – units are in mg/kg

The same analysis also revealed PCB contents of 63 mg/kg (which exceeds the 50 mg/kg limit established by German regulations), Mark et al. (1998).

The proposal for a Directive on end of life vehicles focuses mainly on the banning of four heavy metals (from new vehicles): lead, hexavalent chromium, mercury and cadmium. In the Annex II of the proposal for a directive, some exceptions in materials and components are considered, namely:

- lead as an alloying element (with steel, zinc, aluminum, copper, bronze);

- lead as a metal in components (batteries, fuel tanks, vibration dampers, vulcanizing agent, paint and plastic stabilizer, soldering, wheel balancing weights, spark plugs, spark plugs, pistons);
- hexavalent chromium (corrosion preventive coating);
- mercury (headlamps);
- cadmium (batteries);

According with a report on heavy metals in Vehicles from Okopol, sponsored by the European Union, there are available alternatives to the use of the above-mentioned heavy metals, at least from the perspective of technical feasibility. Many of these alternatives have even reached the state of large-scale industrial application in routine production, Sander et al. (2000).

The above mentioned report also concludes that:

- the manufacturers and suppliers have taken numerous steps to reduce the use of heavy metals in car construction (for which the recent legislative initiatives have been a strong stimulus), although technical solutions still need to be found for alternatives to the incorporation of heavy metals in some components such as spark plugs and soldering in electric and electronic devices.
- the manufacturers will need more time to fully implement the phase-out as formulated in the proposal for a directive on ELV, meaning that some exceptions from the general phase-out appear to be justified.

4.1 Perspectives from different actors

4.1.1 OEM

According with Sander et al. (2000), although alternatives to most heavy metals exist and are often applied, the OEM argue that the following aspects may present some difficulties in the effort for decreasing the use of heavy metals:

- in many cases some new car models are produced without the use of heavy metals in specific applications, but an interim phase out period is needed for older models which will be further produced (e.g. for another 3 years). These interim periods are said to be needed not only because of the car model cycles but also the depreciation period of expensive production equipment has not yet elapsed (e.g. conversion of paint shops is so expensive that it should preferably not be done as an isolated action but rather in combination with other retrofitting measures);
- in other cases, some but not all applications of a certain type (e.g. vulcanizing agent for hoses) are now obsolete, with the remaining ones being much more difficult to substitute (high pressure hoses);
- there may be critical points in the development of a model where normally the heavy metals are not used any longer, but still there is the need to preserve alternative options in case the greener strategies fail (e.g. preventive coatings when corrosion problems are unexpectedly encountered);
- for some components with a long chain of suppliers and sub-suppliers, full implementation of a phase-out is believed to be rather time-consuming and difficult to control;

some solutions which will work in Europe are not feasible elsewhere (e.g. lead free coating of tanks), leading to problems in import and export cars;

4.1.2 First tier suppliers

4.1.3 Component suppliers

4.1.4 National states

4.1.5 European policies

The heavy metals content in the automotive shredder residues, that are sent to landfill, may have significant environmental impacts. This aspect motivated the concern with the ELV processing infrastructure and drove to the preparation of EU legislation, at the present under the form of a proposal for a Directive on end of life vehicles, which stipulates that:

- 18 months after its ratification, new vehicles commercialized after this date can not contain lead, mercury, cadmium or hexavalent chromium, with the exception of some cases referred in the annex of the Proposal for an European Directive.

There is also a strong possibility that in the near future the ASR is reclassified as hazardous waste, what would greatly increase its landfill cost.

The Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture establishes maximum values for the concentrations of heavy metals (namely cadmium, copper, nickel, lead, zinc, mercury and chromium) in soil to which sludge is applied, concentrations of heavy metals in sludge and the maximum annual quantities of such heavy metals which may be introduced into soil intended for agriculture.

The Council Directive 94/62/EC on packaging and packaging waste defines maximum values for the sum of the concentration levels of lead, cadmium, mercury and hexavalent chromium present in packaging or packaging components.

5 The car of the future

The rise in energy consumption, the depletion of finite resources and the environmental impact of a global increase in road traffic have been a focus of growing economic and ecological concern. To answer these problems the following options are available:

- optimization of conventional engine concepts (e.g. new fuel injection systems)
- optimization of traffic mobility through the use of telematics (e.g. integrating traffic information systems, Global Position Systems, Geographical Information Systems and vehicle monitoring systems) and new car ownership concepts (e.g. the Wohn mobil project from Volkswagen);
- use of alternative fuels (e.g. compressed natural gas, liquefied petroleum gas, biodiesel, alcohols, etc...);
- use of high-efficiency, low-emission energy conversion systems (electric, hybrid, fuel cells);
- construction of light weight vehicles (use of magnesium, aluminum, etc...);

Because of their more predictable impacts on car recycling a more detailed attention is to be dedicated to the two last options.

The hibrid vehicles associate two engines: electrical and internal combustion. In some prototypes this last engine's output serves only to provide electrical energy additional stored in the batteries. Their main advantages are the low fuel consumption and low emissions, when compared with normal internal combustion engine driven vehicles.

The electric vehicle, which uses only an electrical engine, presents as main advantages: the good acceleration, the high efficiency and responsiveness, and the low noise and vibration.

In electric vehicles, energy can be stored in batteries or in a fuel tank, in which case a fuel cell is needed to convert the fuel's chemical energy to electrical energy (through a reaction between hydrogen and oxygen). For fuels different from hydrogen, an on board unit is needed, the reformer, which converts these fuels in a hydrogen rich mixture. In comparison to the use of batteries, the use of fuel cells allows for a larger autonomy and power.

The electrical engine major effect on vehicle composition should be the overall increase in the copper content (although iron, aluminum and zinc are also used in electrical engines their relative increase is smaller), which arises the need to promote its effective separation for posterior recycling.

The effects associated with the use of high capacity batteries, namely using nickel metal hydride or lithium are the increase in the content of these materials and the need to develop recycling systems that assure an efficient recovery of these materials.

Fuel cells incorporate significant amounts of noble materials such as platinum and ruthenium. The use, in large scale, of fuel cells made of these materials would further develop the already existent market for recycled noble metals, currently based in the recycling of catalysts.

The construction of lighter, more fuel-efficient, vehicles requires the use of lower density materials and/or innovative technologies (such as multi-material design). Materials are selected with reference to the following factors, Volkswagen (1999):

- Resistance to strain
- Stiffness and strength
- Resistance to temperature and corrosion
- Safety

- Confort
- Attractive cost
- Processability
- Responsible use of materials

Attractive options include optimized lightweight steel construction, aluminum, magnesium, light alloys and fibre-reinforced plastic components.

Trends in vehicle composition show an increase of the lighter materials use. For example, between 1980 and 1994, plastic, aluminum and high strength steel contents of an average US automobile increased from 6 to 8 %, 4 to 6 % and 5 to 8 %, respectively. The content of conventional steel decreased from 52 to 44 %, Keoleian et al, (1997).

The increase in plastics and magnesium contents arises the need for the development of recycling markets for these materials.

The analysis of this problem in a medium-time horizon may not forget the evolving trends in vehicle composition, which is dynamically adjusted as a function of different factors, including environment. For example, between 1980 and 1994, plastic, aluminum and high strength steel contents of an average US automobile increased from 6 to 8%, 4 to 6% and 5 to 8%, respectively. The content of conventional steel decreased from 52 to 44 %. Another factor that may affect ELV composition is the change in the propulsion system, which is the case for the hybrid and electric vehicles.

5.1 Perspectives from different actors

5.1.1 OEM

5.1.2 First tier suppliers

5.1.3 Component suppliers

5.1.4 National states

5.1.5 European policies

6 The regulatory approaches

6.1 *Regulation and competition*

In general, as discussed by Chialin Chen (1994), the objective of public policy for automobile recycling is to pursue the long-term and sustainable solution for this problem. In addition, public policy usually incurs certain levels of benefits and costs to the society. Therefore, the policy-maker should not only focus on the deliberated objective of a specific policy, but also pay attention to the society's overall benefits and costs, such as environmental performance, technology forcing economic impact, and industrial profitability.

Understanding the nature of a problem is the first step in formulating public policies. Automobile recycling is not only a technical issue or an environmental performance, but also an economic practice. Recyclability is a characteristic that has both technological and economic implications. The fact is that current recycling activities are primarily driven by economic opportunity rather than by technological or environmental necessity. Therefore, pursuing the goal of

recyclability not only entails the availability of recycling technologies, but also relates to the economic feasibility for the existing recycling industry.

Automobile recycling is a problem that relates to every sector along a vehicle's life cycle. The barriers which prevent the industry from achieving a higher level of recyclability should be identified from the prospect of the whole automotive system. If any of the elements in the overall system are missing or pose technological or economic barriers, the objective of the public policy to encourage recycling will never be achieved. Therefore, one of the government's primary tasks upon enforcing public policies is to locate and then remove all the obstacles standing in the way of "recovering the maximum amount of resources from the automotive material stream." Instead of unilaterally focusing on a single sector of the industry, the policy-maker should apply a system approach in order to address all the problems along the whole life cycle of automobiles, including product design, manufacturing and consumption, as well as waste separation, recovery, and disposal.

Efficiently adjusting the transfer prices according to different regulatory, technological, and economic conditions may not only rescue the industry from breaking down in some circumstances, but also maintain the industry's overall profitability. In practice, the transfer prices (or the industry's willingness to pay for junked cars and hulks) should be efficiently adjusted to the net values of scrap cars.

However, the real market economics for the industry are composed of a complex web" of financial flows, including the prices of junked cars, used parts, and secondary materials, as well as the costs for dismantling, processing, and disposal. Therefore, the industry should maintain a market system that is able to reflect the correct market signals of all the financial flows, as well as to balance the willingness to pay and willingness to accept within the whole system. Only with sufficient information and an effective market infrastructure can the industry

efficiently adjust its economic system in response to all the uncertainties and risks associated with automobile recycling.

Automobile recycling is an inter-sectoral problem that relates to every sector along an automobile's life cycle. In order to resolve the problem from a system approach, it is necessary to encourage inter-sectoral cooperation among all the actors in the industry. In practice, a strong partnership should be established among materials suppliers, manufacturers, dismantlers, shredders or even consumers. Material suppliers can highlight the positive and minimize the negative attributes of materials. Dismantlers and shredders can provide manufacturers with separation and processing expertise so that the automakers can incorporate the concept of "design for recycling" into their design and production processes. Consumers can express their concerns on product consumption and environmental quality. Additionally, material suppliers and manufacturers can work closely to create secondary markets and explore applications that can encourage closed loop recycling.

In addition, the government and the industry should support and fund the R&D for automobile recycling, not only in the field of technological development, but also in the areas of economic analysis, market survey, and even the policy evaluation of foreign recycling imperatives. It turns out that the more technological and market information we control, the fewer risks and uncertainties will be involved in our decision-making processes.

Finally, all the affected parties should pursue the same objective: to reduce the solid wastes generated, decrease the virgin materials extracted, and support the long-term development of the society. Under the same belief and through the joint effort by the government, the automotive industry, and the general public, a

sustainable solution for the domestic automobile recycling problem will be on its way.

6.2 Proposals

Main drivers

Uniform regulation in member countries concerning the classification of ASR and its disposal landfill costs.

Uniform regulation concerning roadworthiness testing.

Creation of an European green rating system for autos considering, together with other environmental impacts (such as the exhaust emissions and the fuel consumption), the non recyclable waste production.

Global context

Creation of an European public entity devoted to promoting pre-competitive research on auto recycling

Promoting the export of ELV to countries outside the EU

European vision

To promote the implementation of a system that allows the precise quantification of the European Union ELV flux

Heavy metals

Sander et al. (2000) suggests:

- Definition of quantitative reduction targets
- Identification and labelling of heavy metals to be separated at the dismantler's (manufacturers should make information available for dismantlers, through the IDIS system not only concerning future exceptions from the general phase out but also about heavy metals in existing cars)

Attribution of additional incentives to dismantlers and/or intensification of the controls on dismantling quality, to ensure the extraction of components containing heavy metals. This is because, even with improved design for recycling, the dismantling and separate disposal of some components will significantly increase dismantling costs (e.g. mercury containing bulbs and lighting elements);

6.3 *Methodological Approaches*

Heavy metals

There is the need for accommodating justified requests for interim periods without jeopardizing the goal to phase out the use of lead, cadmium, mercury and hexavalent chromium in automobiles. Sander et al. (2000) refers that possible instruments would be the definition of quantitative reduction targets related to time-scales in combination with a systematic monitoring of the progress achieved in terms of reduced heavy metal consumption in new car models, and in terms of reduced heavy metal contamination of the steel scrap, the heavy and the light fractions after shredding of ELV.

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8 ANNEX I – GLOBAL CONTEXT

8.1 USA

Recycling falls well behind cost considerations in order of importance to US automakers, according to a survey by the Society of Automotive Engineers. While recycling, along with quality issues, was high on the agenda a few years ago, both have declined in stature. The three major automakers can claim to have tackled quality problems, but recycling has slipped away, not because the industry has dealt with the problem, but because whatever public pressure was behind, the issue has disappeared, Wright et al. (1998).

In the beginning of the 90's, automakers were concerned that legislation would force them into the recycling business, following the European example. In addition, the existing auto recycling infrastructure complained about the growing use of plastics. Auto fluff – the material left after recyclers extracted valuable products including steel and non ferrous metals – was expanding as a percentage of the total car, and recyclers worried that the fluff would become more expensive to ship to landfills, Wright et al. (1998).

The plastics industry responded pro-actively to these concerns, making efforts to improve resin labeling of parts, design products for easier disassembly, and set up pilot projects to recycle plastic components. In some cases, the projects have grown into commercial successes, Wright et al. (1998).

In most states, ASR is designated as non-hazardous waste, and it is disposed in Resource Conservation and Recovery Act Subtitle D landfills. In California, ASR does not meet cadmium restrictions; therefore a chemical fixation is required which adds \$20 per ton to the tipping fee. Other states require treatment of ASR to immobilize heavy metals or have imposed other regulations on ASR disposal, Keoleian et al. (1997).

8.1.1 Fleet and ELV flux

In the United States of America the number of circulating passenger vehicles increased from 124 million in 1982 to a maximum of 147 million in 1994, after which decreased to 131 million in 1997 (in this year there were 2 inhabitants per vehicle). The mean age of the vehicle population was of 8,1 years, compared to 5,5 years in 1970, ACAP (1999) and Keoleian et al. (1997).

The number of retired passenger vehicles in 1993 was of 7,3 million (varied between 6 and 11 million units in 1983 and 1992, respectively). In 1990 the median end of life passenger vehicle had an age of 11.77 years and a mileage of 100,500 miles (161000 km). Around 6% of the ELV are abandoned, often in rural areas, which are too remote from dismantlers for economical transportation, Keoleian et al. (1997).

USA has around 182 shredders and 6000 dismantlers. A typical dismantler processes 400 to 500 cars per day. The scrap industry recycles approximately 10 million tons per year of shredded iron and steel (which is equivalent to the output of two average steel mills), Keoleian et al. (1997). Many of the automotive dismantlers in North America are connected through an on line database known as the Hollander system. This system allows dismantlers to check prices for parts available for resale at other dismantlers. When interested in a particular part, the system performs a search beginning in the local area and expanding until a good sample of parts at various dismantlers has been investigated, Ramirez (1996).

Under current recycling conditions, Oak Ridge National Laboratory estimates that ASR disposed in landfills will increase from approximately 2.2 million tons in 1992 to 2.5 million tons in the year 2000 (this accounts for about 1 to 1.5 % of the total Municipal Solid Waste), Keoleian et al. (1997).

8.1.2 Partnerships for a greener vehicle

In 1992 the three American OEM, DaimlerChrysler, Ford and General Motors, formed the United States Council for Automotive Research (USCAR), an

umbrella organization destined to further strengthen the technology base of USA auto industry through cooperative, pre-competitive research (see <http://www.uscar.org/>).

In 1993 the USCAR and the US federal government formed the Partnership for a New Generation of Vehicles (PNGV), which is an historic public/private partnership between the U.S. federal government (led by the Technology Administration at the Department of Commerce, and including 7 agencies and 19 federal laboratories) and Daimler Chrysler, Ford, and General Motors that aims to strengthen America's competitiveness by developing technologies for a new generation of vehicles (see <http://www.ta.doc.gov/pngv/introduction/intro.htm>).

Announced at the White House on September 29, 1993 by President Clinton, Vice President Gore, and the CEOs of the domestic auto makers, this national government/industry research program also includes research support for over 350 automotive suppliers, universities, and small businesses.

PNGV's long term goal, dubbed the "Supercar" goal , is to develop an environmentally friendly car (production prototypes should be produced by each car company until 2004) with up to triple the fuel efficiency of today's midsize cars--without sacrificing affordability, performance, or safety. This "Supercar" should also achieve a recyclability objective of at least 80%, up from 75% industry average today.

In what relates to the development of specific technologies for recycling, reuse and recovery the USCAR includes two teams the Vehicle Recycling Partnership (VRP) and the United States Automotive Materials Partnership (USAMP).

The VRP was established in November, 1991 with the collaboration of the Automotive Recycler's Association – ARA (that represents dismantlers), the American Plastics Council (APC) and the Institute of Scrap Recycling Industries – ISRI (representing vehicle shredders). This partnership was formed to identify and pursue opportunities for joint research and development efforts pertaining to recycling, re-use and disposal of motor vehicles and vehicle components. The

partnership also will promote the increased use of recyclable and recycled materials in motor vehicle design.

VRP has the following goals: (1) reduce the total environmental impact of vehicle disposal, (2) increase the efficiency of the disassembly of components and materials to enhance vehicle recyclability, (3) develop material selection and design guidelines and the (4) promotion of socially responsible and economically achievable solutions to vehicle disposal. To achieve this goals, VRP has promoted a number of projects, such as (see <http://www.uscar.org/consortia/con-vrp.htm>):

- Field study about the economical viability of plastic recycling, which involved a dismantler, a waste separation company and a plastics recycling company that determines if it needs to be combined with virgin material, and what would be the best use for the material.
- Development, together with the American Plastics Council and a recycling company, of the “skin-flotation” method, which is to be used for the separation of the plastic materials present in automotive shredder residue (ASR). In this method ASR is introduced in a hot water bath, together with some chemicals, which react only with certain plastics and cause air bubbles to attach to the plastic and float. They are then skimmed off of the top of the water bath. While skin flotation is currently slightly more expensive and time consuming than necessary to make it commercially viable, if perfected it could lead to a much higher percentage of plastics being recycled rather than shredded and sent to landfills. Rubber recovery also is being assessed as a part of this project. Since rubber contaminates plastic materials, it's very important to separate it from plastics. This involves first using skin flotation, which causes most of the plastics and a small amount of rubber material to bubble and float. Then, a process called air aspiration is used to remove the rubber from the plastic materials

obtained from the skin flotation. When air aspiration is used, material goes through a conveyor and when it hits a certain point, an air-suction tube sucks lightweight materials (plastics, textiles, foam) up the tube and heavy materials, such as rubber, will fall out of the material stream.

- Field study to assess the economical viability of wind shield recycling which involved a wind shield replacement company and two waste collection companies.

ARA's involvement with the VRP also gives it a means to communicate directly with automakers and parts makers. In the past, manufacturers cared little for the problems encountered by scrapyards operators and scrap dealers. But now, with a greater awareness of recycling and a fear of governmental mandates for "green" cars, manufacturers are not only paying more attention to the materials they put in vehicles but also looking at how parts and assemblies may be designed for easier disassembly, Wright et al. (1998).

The VRP opened a facility in Highland Park, Michigan on the Chrysler Center site and named it the Vehicle Recycling Development Center. This center is a meeting place for people to discuss vehicle recycling issues. As well, it is an active research center where time-studies are conducted and recorded, and materials are identified and sorted for recycling, Ramirez (1996).

The Aluminum Association will be an important collaborator to the VRP consortium. As aluminum usage grows in cars and light trucks, the automotive industry can benefit from the association's existing network of task groups to develop automotive recycling guidelines, model the recycling stream for auto aluminum scrap and survey the aluminum practices in the dismantling community. Automotive aluminum recycling is already a success, with 85 to 90 % of vehicle aluminum reclaimed and recycled. Recycling aluminum offers additional advantages, saving energy, reducing emissions, minimizing waste and bringing economic value, Wright et al. (1998).

USAMP was formed in June 1993, with the purpose of conducting vehicle-oriented research and development in materials processing to improve the competitiveness of the US auto industry. Its goals are (see <http://www.uscar.org/consortia/con-usamp.htm>):

- the conduction of joint research to further the development of lightweight materials for improved automotive fuel economy the seven major technology groups are:
 - polymer composites
 - light metals (including aluminum, magnesium and metal-matrix composites)
 - engineered plastics
 - cast iron
 - steel
 - ceramics
- to work with the Federal government to explore opportunities for cooperative programs with the National Laboratories, Federal agencies such as the Department of Energy and universities.

8.2 Japan

Japanese, South Korean and other Asian carmakers generally see recycling as part of the total environmental compatibility of their vehicles and not as a separate issue. The consensus is that they will follow the legislative lead set by Europe, Wright et al. (1998).

In Japan the number of circulating passenger vehicles has increased from 40,7 million in 1993 to 48,6 million in 1997. In 1997 there were 2,6 inhabitants per passenger vehicle, ACAP (1999).

The issue of recycling of end of life vehicles has also been considered a priority in Japan, where in 1990 a law for the promotion of use of recycled resources, applying in particular to automobile and household appliances industries, was passed. In addition, in October 1996 the Ministry for International Trade and Industry (MITI) drew up a set of quantified targets for the recycling of end of life vehicles (85% by 2002 and 95% by 2015). MITI also called for a drastic reduction of the use of lead in new vehicles.

The Japan Automobile Manufacturing Association (JAMA) set the following recycling targets (see <http://www.nissan.co.jp/INFO/RECYCLE/E/02.html>):

- By the end of 2000: a reduction of lead content in new models (excluding batteries) to one-half of 1996 levels;
- By 2002: new models should be recyclable in more than 90 % (at the design process);
- By the end of 2000: a reduction of lead content in new models (excluding batteries) to one-third of 1996 levels;
- By 2015: new models should be recyclable in more than 95 %, Wright et al. (1998);

According to JAMA statistic, current recycling rate of ELV is 75 % on average (per mass).

According with Wright et al. (1998), pressure towards ELV recycling may not be as high in Japan due to:

- The age of the Japanese circulating fleet. Only around 18 % of cars are over 10 years (world average is 36 %) old and 29 % are less than 3 years old;
- The high volume of exported used cars. Japan exports its used cars at the rate of 360,000 a year, about of which 100,000 go to New Zealand. Other destinations include Ireland, the Caribbean, Pakistan, Russia and Latin America. There is also a thriving export market in Japan for second-hand parts from scrapped cars.

8.2.1 Mitsubishi

Today, about 75% by weight of the scrapped car body can be recycled for reuse. Mitsubishi Motors are carrying out research work to raise this recycling rate up to 90% or more by the year 2000. To mention a few examples, such materials are selected as can be recycled easily and identification codes are marked on the plastic parts that have weight of over 100 g, for clear indication of their kinds. Further a new technology has been developed by Mitsubishi Motors for easy removal of paint coating, so that the painted parts may be recycled. As the results of these efforts, the demounted bumpers can now be re-processed to the new bumper or for interior materials. Tangible outcome has been achieved in these efforts (see <http://www.mitsubishi-motors.co.jp>).

Apart from the re-utilization, longer service life of materials also contributes to the resource-saving. Mitsubishi Motors are working for development of longer life oil products and have successfully achieved the longer life brake oil and coolant material, reducing the exchange frequency at the time of car inspection. Further a transmission oil has been developed which needs change only after 100,000 km run or more. It is being commercially applied to the new model cars stepwise.

Mitsubishi Motors says that the co-operation of suppliers is indispensable in the development of easily recyclable vehicles – both for the use of materials and in the adoption of body structures that are easier to disassemble, Wright et al. (1998).

8.2.2 Nissan

Nissan, together with other Japanese vehicle manufacturers, formed the Recycling Promotion Committee in August 1990 with an eye toward promoting effective utilization of natural resources, reducing waste and protecting the environment. To step up recycling activities further, the Recycling Promotion Department was established in May 1996.

Nissan established as target, to achieve the previously mentioned recycling rate of 90 % (defined by JAMA for 2002) in the year 2000 (see <http://www.nissan.co.jp/INFO/RECYCLE/E>).

In February 1998, Nissan announced its Voluntary Action Plan for Vehicle Recycling, which explains the efforts Nissan is making as a manufacturer in line with the " Initiatives to Recycle End-of-Life Vehicles (ELVs) " announced by the Ministry of International Trade and Industry in May 1997. Some examples of these efforts are (see <http://www.nissan.co.jp/INFO/RECYCLE/E>):

- Recycling of automobile components in the same automobile components through the recycling of automobile carpets (incorporating up to 30 % of recycled material in the new components).
- Recycling of automobile components in other auto components as is the case with bumpers which are recycled into: engine bottom cover, footrest, trunk trim and battery case.
- Recycling of other industries' recycled materials into auto parts through the use of recycled PET bottle fiber to make insulators. Through a joint project with Mitsubishi Chemical Corporation, Nissan has succeeded in developing the technology for fabricating fine-diameter fiber from recycled PET fiber, which was previously difficult to accomplish. The fiber from used PET bottles is recycled and applied as the main component of the sound-absorbing layer of the dashboard insulator and the floor insulator (incorporating up to 60 % of recycled material).
- Development of an engine coolant recycler
- Developing technologies for separating various types of crushed materials with high accuracy and efficiency.
- Conducting pilot research to develop efficient dismantling techniques in order to promote ELV appropriate treatment,

materials recycling and reuse of parts. In September 1996, Nissan issued a Dismantling and Recycling Manual aimed at advancing ELV appropriate treatment. A research project was commissioned to a dismantler in Yokohama, Kanagawa in October 1997 with the aim of demonstrating that the procedures described in the manual could be implemented in an actual dismantling shop. The dismantler has been evaluating the procedures by performing them exactly as they are explained in the manual. This dismantling research project is aimed at developing methods and technologies for appropriate treatment of harmful substances, such as waste oils and lead resulting from the dismantling process, so as to improve their recycling rate and avoid polluting the environment. Another major objective is to make the information and technical expertise obtained from this research publicly available to related industries. A used auto parts store was opened in November 1997 next to the pilot dismantling plant to undertake research on quality control and logistics questions concerning reusable parts. Serving as an antenna to sense public reaction, the store has initiated a full series of activities, including the collection of reusable parts from the dismantling plant and management of used part inventories and sales.

Nissan sees the energy recovery of shredder residue as an essential means for attaining the target of reuse and recovery rate of ELVs from 2002 onward, which all related industries are now working to achieve. Toward that end, Nissan built a test plant of cokeless cupola for the direct melting of shredder residue at the Oppama Plant in July 1997 together with a plant manufacturer and a shredder operator and launched an experiment to demonstrate the feasibility of energy recovery technology. The results of this research will be furnished to related industries for the purpose of improving the reuse and recovery rates of ELVs.

8.3 South Korea

In South Korea the number of circulating passenger vehicles has increased from 4,2 million in 1993 to 7,5 million in 1997. In 1997, there were 5,9 inhabitants per passenger vehicle, ACAP (1999). The main manufacturer is Hyundai.

Hyundai says it plans to use recyclability as a significant part in its marketing strategy. 'Hyundai is trying to become a kind of company which customers regard as a car manufacturer producing environmentally-friendly cars'. But Hyundai also believes that "customers need to participate in these recycling efforts by paying for this investment in technology", Wright et al. (1998).

One of the chief areas of concern is whether or not Hyundai is prepared to meet all legislation requirements. Hyundai believes that customers and owners should be responsible for ELV's – making OEM responsible would mean including the collection fee in the price of a new car which would directly affect sales. But manufacturers and importers need to set up recycling programs with other manufacturers in certain markets as long as the relationship can reduce the cost, or make recycling more effective. Joint recycling programs could be much better in some areas, Wright et al. (1998).

South Korea has the youngest car fleet in the world with just 0,35 % of vehicles more than 10 years old (against a world average of around 36 %) and 55 % being under 3 years old. According with Wright et al. (1998) this may in part explain why South Korea has a more relaxed view on ELV recycling.

8.4 The European vision

Over the last 30 years, the car has become one of the most important consumer products in industrialized society – second only to the home as the single most expensive purchase by an average family. Yet it is discarded within a relatively short time, typically between nine and 13 years and its disposal, unless handled correctly, can have a major environmental impact, both in terms of waste products and in the recovery of original materials to conserve resources.

In the EU the number of circulating passenger vehicles increased from 102,6 million in 1980 to 167 million in 1997 (in this year there were 2,2 inhabitants per vehicle), ACAP (1999) and Eurostat (1998).

The annual waste flux due to end of life vehicles (ELV), of the categories M1 (passengers vehicles comprising no more than eight seats in addition to the driver seat) and N1 (vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes), in the European Union is quantified in around 8 to 9 million tones (in *Proposal for a Parliament Directive on end of life vehicles in the European Union 8095/1/1999 – C5 - 0180/1999 – 1997/0194(COD)*).

This aspect motivated the concern with the ELV processing infrastructure and drove to the preparation of EU legislation, at the present under the form of a proposal for a Directive on end of life vehicles, which stipulates the following targets:

- 18 months after its ratification: new vehicles commercialized after this date can not contain lead, mercury, cadmium or hexavalent chromium, with the exception of some cases referred in the annex of the Proposal for an European Directive.
- Until 01/01/2006 – valorization of 85 % (recycling 80 %) for vehicles produced after 1980, per mass

- Valorization of 75 % (recycling 70 %) for vehicles produced before 1980, per mass
- Until 01/01/2015 – valorization of 85 % (recycling 85 %), per mass

These targets are to be achieved ensuring that the deliver of the ELV is done at a certified treatment facility and without costs for the last owner.

(in *Proposal for a Parliament Directive on end of life vehicles in the European Union 8095/1/1999 – C5 - 0180/1999 – 1997/0194(COD)*).

Estimates presented by a study from two consulting companies for EUROSTAT, indicate, for the period between 1990 and 1994, fluxes of ELV in the EU, oscillating between 8,200,000 units in 1990 and 9,700,000 units in 1992. There is a certain amount of uncertainty associated with these values, related with the quantification of the ELV fluxes in each country.

More conservative estimates are provided by a report from MAVEL commissioned by the Association of Plastics Manufacturers in Europe which indicates the following values for the ELV flux in the European Union: 9,3 million in 1990, 6,3 million in 1994, 8 million in 2000 and 9,5 million in 2010, MAVEL (1997).

This report also states that:

- The number of ELV will continue to grow from 1996 to 2015
- The number of ELV can vary significantly from one year to another
- Significant variations from region to region within the same country can be observed
- Previously the number of ELV has very often been overestimated (because exports of second hand cars to third countries were underestimated and official car fleet figures have not been corrected)
- The political changes in Central Eastern Europe have created a very special situation in Germany

8.4.1 ECRIS project

The Environmental Car Recycling in Scandinavia (ECRIS) was initiated in 1994 as a four year research and development project involving Volvo Car Corporation (VCC), Stena Bilfrågentering AB, AB Gothard Nilsson and Jönköpings Bilfrågentering AB. The aim of the project was to develop an efficient system of recycling cars in an ecologically compatible manner. The system was to be designed initially for Swedish conditions, with provision for extending it later to the rest of Scandinavia, ECRIS (1998).

The ECRIS AB company was formed to conduct the project in cooperation with the Swedish Association of Motor-Car Scrappers (SBR), the Association of Swedish Automobile Manufacturers and Wholesalers (BIL), researchers from various Swedish third level institutions and research institutes, and specialists from other industries involved, ECRIS (1998).

The ECRIS project comprehended the following sub-projects:

Life Cycle Assessment - use of LCA methodology to develop an analytical tool for evaluating the environmental impact of various recycling options;

Methods and Tools – development of methods and tools for dismantling and sorting environmentally hazardous components as well as recyclable materials;

Materials recycling – to compare and evaluate the feasibility of recycling various materials;

Energy recovery – to analyze the feasibility of recovering energy of landfill wastes

Hazardous wastes – analysis of different materials for environmentally hazardous substances and with the environmental impact of these materials when burned to recover the energy content.

Economics – evaluations of the economic consequences of expanded recycling activities

One of the main conclusions of this project was that over emphasis on the recovery of polymeric materials will not reduce the environmental loading and in order to achieve higher recovery rates in the future, it will be necessary to permit a 'mix' of materials recycling and energy recovery.

8.4.2 FARE

The Fiat Auto Recycling – FARE – was initiated by Fiat in 1992. F.A.R.E. also includes businesses belonging to the Association of Italian Auto Demolition Companies and several manufacturers of chemicals, metallurgical products, glass and plastics. Fiat dealers and branches routinely accept cars ready for dismantling. As of the end of 1998, the over 300 authorized demolition centers located in all the regions of Italy, which had joined the system, had processed 1,140,000 vehicles, Fiat (1998).

This project takes a “cascade” approach to recycling vehicle components, which takes into consideration the degradation of the physical properties of plastic materials during their life cycle. Fiat engineers conceived a system with different levels of requirement for the quality of non-metallic materials. A classic example is given by bumpers made of polypropylene, whose physical properties are degraded during their use phase (namely impact resistance), due to solar radiation and other exterior effects. Although recycled polypropylene is not fit to make new bumpers, it may be used to produce other components subject to less demanding physical requirements, thus descending a level in the “cascade”. Efforts should also be addressed to find solutions for recycled materials in other industries, besides the automobile industry. At the end of 1998, the following quantities had been recycled under the FARE project:

19,200 ton of glass (mainly for bottles);

5,400 ton of bumpers (in air ducts and interior trim in new Fiat models, and other products);

6,600 ton of seat padding (for carpet padding and soundproofing material for new models);

4,000 catalytic converters;

Fiat claims to have anticipated the implementation of the EU directive by helping to create a system that will permit recycling rates of 85% by 2002 and 95% by 2010, including 5% in energy recovery.

The dismantlers associated to FARE, perform a selective disassembling not only of Italian OEM (Fiat, Alfa Romeo and Lancia) but also from other European makes (e.g. Renault, Peugeot, etc...), that signed agreements of mutual cooperation with Fiat.

The number of vehicles processed by the FARE system presented a particular increase in 1997, which may be, in great extent, explained by the attribution of ELV dismantling incentives by the Italian Government in that year.

8.4.3 ARN

In the Netherlands, a concept is used which was initiated by the Dutch car sector (car dismantlers- STIBA; car manufacturers and importers- RAI; car garages- BOVAG; damage repair companies- FOCWA; and the Dutch Shredders' Association- SVN) in compliance with the Dutch Environmental Law. The Dutch Shredders' Association no longer exists and thus is no longer represented on the board. In 1993 it was founded a private firm called Auto Recycling Nederland BV to administer the waste disposal fees and to allocate the premiums. Since January 1995, more than 1,000,000 ELV were processed by ARN (1998)

The shareholders determine the main lines of policy to be followed by ARN. The foundation is advised by the Advisory Board, on which the government and other interested parties such as environmental and consumer groups are represented (source: Auto Recycling Nederland ARN).

The concept is supported by the Ministry of Housing, Regional Development and the Environment and it aims on drastic reduction of the amount of dumped waste from ELV's up to 86 % in the year 2000 in an environmentally responsible way. To achieve these aims they make use of a 'Waste disposal fee' to finance a fund created. The fee (initially, in 1995, with the value of 250 NLG and after decreased to 150 NLG) is added to the car's purchase price and is paid when a Dutch car licence is first issued for a vehicle with four or more wheels and with an empty weight and loading capacity of maximum 3,500 kg. The legislation covering car registration lays down that a vehicle cannot be registered before a waste disposal fee has been paid (source: ARN).

Recycling premiums are paid to dismantlers, in order to promote additional dismantling and recycling. Additionally, ARN pays premiums to transport companies and to recycling companies. They have implemented, as in Germany, a Certificate of Disposal and a certification scheme for dismantlers. The ownership tax is linked to the Certificate of Disposal. There is a free of charge take back obligation for all Dutch cars, which also takes into account the proposal of the European Directive concerning ELV's, Stork (1999).

ARN seeks for recycling possibilities, makes premiums available for non-profitable recycling activities, mediates between dismantling companies and recycling companies and provides an infrastructure and guaranteed volumes of materials. The dismantling companies have to become business partners of ARN. They must comply with a number of objective standards that are tested by a qualified certification company. Additionally, they must dismantle certain specified materials in certain specified ways. In return, the dismantlers receive recycling premiums for supplied volumes of material. At the moment ARN pays 155,14 NLG for each ELV.

The car dismantling companies undertake to accept car wrecks free of charge, dismantling them in accordance with the standards and issuing the owner with an indemnity certificate. This document exempts the owner from car tax and other legal obligations such as insurance and the periodic roadworthiness test (APK)

(source: ARN). In the Netherlands there 11 shredders and 907 car-demolition licence holders registered. Of these, 277 are registered with ARN.

In 1998 (1997) a total of 699,848 (624,477) cars were registered for the first time in the Netherlands and ARN processed 232,685 (237,266) car wrecks, which corresponded to 90 % (88 %) of all the car wrecks processed in the Netherlands. About 32 % of the Dutch ELV's are exported (source: ARN).

Another interesting number is that the recycling costs in 1998 (1997) were NLG 47,535,592 (56,311,531) and the total quantity of material recycled was of 19,966,535 (19,525,049) kg and of 1,694,933 (1,648,425) ltr of oil and coolant (\pm 1,694,933 kg respectively 1,648,425 kg), and thus 21,661,468 (21,173,474) kg of recycled material in 1998 (1997). Thus, the recycling of ARN materials costs about NLG 2194/ ton (2660/ ton), ARN (1997), ARN (1998).

The quality of the participating companies is assessed every year in the course of an inspection based on requirements drawn up previous to the inspection round (source: ARN). The inspections are carried out by SGS (Société Générale de Surveillance).

Because of the strong objections on the part of the waste incineration plants and the practice of no acceptance of the shredder waste, the legislation forbidding the dumping of shredder waste was retracted as of 15 January 1998. Because the dumping of shredder waste is not as expensive as it is in Germany, the Dutch shredders can pay more money to dismantlers than German shredders. This leads to the import of German ELV's, originating from German dismantlers.

8.4.4 ACORD and CARE

Statistics show that around 1.7 million cars and 200,000 vans were scrapped in 1997 (an above average year), which would equate to just over 2 million tones of material from which were sent to landfill around 502 tones (around 25 %). The average age of an ELV is currently just under 14 years, ACORD (1998).

In 1997, in the United Kingdom, a voluntary inter-sector agreement on the treatment of ELV was signed between the Society of Motor Manufacturers and Traders (SMMT), the British Metals Federation (BMF), the Motor Vehicle Dismantlers Association (MVDA), British Plastics Federation (BPF) and the British Rubber Manufacturers Association (BRMA). The signers of the agreement are committed to achieve a rate of material recovery of 85 % in 2002, for which the following actions are envisaged, ACORD (1998):

- increase plastic recovery by better separation processes;
- develop applications/markets for recycled plastics;
- increase recovery of fluids by more effective depollution;
- reduce residual metallic content of shredder residue;
- improve tire and other rubber recovery process;
- initiate glass recovery process;
- develop ASR energy recovery process;

The members of ACORD acknowledge the Commission's motive for a Directive, primarily to accelerate the process of environmental protection through waste minimization and material recovery and, secondly, to harmonise approaches to ELV recycling throughout the European Community.

Industry welcomes the concept of ensuring that ELVs are handled only by authorized facilities, and the proposal for certificates of destruction to be used as a control mechanism. However, the latter would have little effect in the UK, unless it is accompanied by some motivation for the last owner to obtain one. Overall, however, Industry questions the necessity for the Directive as drafted on the grounds that many of its conditions are already being met by the industry, while many others are considered to be either unworkable or likely to incur unnecessary costs for the consumer. The Dismantling Industry is concerned that, without funding for uneconomical processes, the requirements of the Directive cannot be fulfilled.

It is also considered that the ACORD agreement sets out similar objectives to the EC Directive but with several key differences:

It is voluntary, non marque-specific and does not require subsidies;

It is based on progressively improving environmental performance while maintaining the viability and independence of the existing operators and infrastructure;

It proposes limits on landfill rather than specific re-use and recycling targets, achieving the same environmental result but leaving the method to be determined on economic or environmental grounds;

Given a more positive approach to thermal recovery, much of the residue which is currently landfilled, apart from glass, could be used for fossil fuel substitution;

The existence of the ACORD voluntary inter-sector agreement and similar agreements in many other countries in Europe, all of which set out to meet similar objectives in a similar time frame, make the need for a Directive highly questionable.

In the UK there is also another industry consortium, called CARE, which was created by a group of ten leading OEM (which together account for around 75 % of UK car sales), which has a network of 30 associated dismantlers. This consortium has developed pilot projects in the following areas, ACORD (1998):

- improving depollution techniques,
- trials to collect, regrind and recycle polypropylene bumpers, ABS plastic parts, polyester material from seatbelts, seat foam
- recovery of copper from wiring looms
- energetic valorization of tires (50,000 processed up to date)
- analysis of ASR to determine contamination levels and potential processing necessary to convert it into a usable fuel

8.4.5 ARGE-Altauto

In Germany, in 1998, 3,468,798 passenger vehicles of the M1 class were deleted from the National Car Registration Office located at Flensburg (source: Kraftfahrtbundesamt KBA). It is estimated that around 50 to 60 % of these ELV were exported, mainly to Eastern Europe countries, the main reason being the exigent periodic roadworthiness test, performed in Germany, Stork (1999).

On April 1, 1998 the "Ordinance on the Disposal of ELV and the Adoption of Road Traffic Regulations" ("ELV-Ordinance") and the Voluntary Agreement ("ELV-VA") for the environmentally friendly ELV processing (Passenger Cars) within the Ecocycle-Law came into force. In 1999 there were 4859 certified collection points and 1034 certified dismantlers. The number of dismantling facilities decreased around 67 %, after April 1, 1998, due to the implementation of the certification system proposed by the ELV- Ordinance, ARGE-Altauto (1999), Stork (1999).

Under Altauto V the dismantlers are obliged to perform the ELV deppolution (removal of fluids, tires, batteries) and dismantling facilities should comply with several requirements, such as to have: well defined areas for each activity (such as delivery, deppolution, storage of reusable components, etc...), waterproof and acid resistant floor and a draining and separation system for oil recovery.

Currently the last owner may have to pay (between 50 and 150 DM) for delivering the vehicle at a certified collection point.

9 ANNEX I – DISMANTLING TECHNOLOGIES

The employment of techniques, equipments and tools for dismantling are based on:

- throughput of ELV's
- condition of the ELV
- diversity of car models and variants
- organisation of the processing and the work
- connection techniques
- dismantling quantity

The organisation of the processing and the work at the dismantling yard is based on the working methods of the automobile industry and the car garages.

It has to be distinguished between two fundamental principles:

- *line* (central) in with dismantling lines
- *decentralised* in with small dismantling yards

The actual realisation of dismantling yards and process organisations could also bring the combination of both principles. The *line* principle could be, for instance, combined with the *decentralised* principle in certain parts of the company. This solution comes up when there is a great dismantling throughput. The rough dismantling is made in line and the dismantling of groups of parts is made with the decentralised principle.

In the following sections the different principles are described with some examples.

9.1 Dismantling line

Dismantling lines are operated as semi-automatic lines with defined time intervals. At the disassembly stations, defined car parts are disassembled. The required tool equipment is combined with the disassembly requirements.

There are a few producers of dismantling lines: AMB, CRS, Noell, Schenk, Sket and others. As an example for a semi-automatic dismantling line there is the concept of the company G.A.T, which will now be described in a simplified way. The realisation of the project was planned with the company Aumund Förderbau (conveyor equipment) for a dismantling yard in Leipzig. The concept consists of eight stations. The transport of the car bodies is made via a carrying chain conveyor.

In the first station the tyres are removed, including the spare tyre. Furthermore, the battery is removed. Afterwards, the vehicle is led another station (2) where the removal of all liquids is made. The liquids are sucked with adequate drain-off equipment and stored in different recipients. Subsequently, the tanks are removed. To separate the tanks from the car body some hydraulic shears are employed.

In station 3, the boot, the engine bonnet and the radiator are disassembled. The engine is torn off with the engine tearing equipment. What follows is the dismantling of the shock absorber and the front axle.

The stations described are operated in two lines. Afterwards, the car bodies are crosswise transported via a conveyor and subsequently they are transported again in line to station 4. Here, the screens are removed using sucker equipment for the transport and handling. Afterwards, the doors, the tailgate and, if it exists, the glass roof are removed.

In station 5 the bumpers, the lamps, outside plastic parts and the windscreen wipers are dismantled. In station 6 the roof is separated from the car body using some hydraulic shears. Interior plastic parts and the dashboard are also

removed. These parts are collected in different containers. Afterwards, in station 7, the parts at the bottom of the ELV are dismantled. Turn over equipment allows the easy access at the bottom. The remaining car body is then pressed in station 8 and it is transported to the storage for processed ELV's with a conveyor.

This factory concept is based on the estimation of a throughput of 50 to 80 ELV's per shift. The time interval is between 3 and 5 minutes.

The advantage of the dismantling line is the possibility of having a high throughput of ELV's. This requires the employment of destructive processes in some cases to cut connections, what stands in opposition to the reuse of these car parts or components.

On the other hand, the dismantling of the ELV's is also possible without the employment of destructive processes, if the time intervals are correspondingly extended. In this case, the throughput of the dismantling line has to be diminished (based on Härdtle et al, *Altautoverwertung*, 1994).

The possibility of having a high throughput of ELV's could also be a risk because of the lack of ELV's in some countries. According to the experiences made in Germany and the Netherlands, the owner of dismantling lines sometimes could not guarantee the minimum number of ELV's required to work in an economically viable way and thus have gone into liquidation or have big financial problems.

Another problem is the high investment to be made for the dismantling line, a CRS-Car Recycling Systems line costs about 700.000 DM, and the high wage costs for the numerous staff who is needed to run the dismantling line.

Another problem could be the market for reuse products, a problem caused by the centrality of the dismantling lines. Parts for reuse, which in the grade list of recycling are at the top of the list, could not be sold because of long distances for the clients to the next dismantling line or not availability because of destructive processes in use.

Some car manufacturers have prepared dismantling handbooks, which could be used as a base for the conception and the operating of dismantling companies.

In this context the IDIS (International Dismantling Information System) software of the EUCAR (European Council for Automotive Research & Development) council has to be named. There already exists the versions 1.0 and 1.05, including information from the European vehicle manufacturers, and the version 2.0 is in preparation, also including information from the Japanese vehicle manufacturers. The current software, version 1.0.5, contains information about recyclable materials, information on dealing with pyrotechnic components, information about tools and dismantling techniques. Additionally, it is possible to print model specific component check sheets and manuals for the use of dismantling operators.

A limitation for the conception and the operating of dismantling companies using this data is given by the specificity of the car models and the different conditions of the vehicles (corrosion, accident and age).

9.2 *Dismantling yards*

Dismantling yards operating according to the decentralised principle have a great flexibility according to the dismantling quantity, as well as to the conditions of the dismantled ELV's (accident, age, etc.). In contrast with the dismantling lines, time intervals for the stations are not necessary in dismantling yards. Therefore the dismantling of vehicles with different dismantling quantities (cars involved in accidents, partly dismantled ELV's) do not cause any problems. The decentralised principle is mainly applied to small companies, which process only a few vehicles per yard, although they process almost the whole quantity of vehicles processed in European states

The concept is based on a throughput of a maximum of 10 ELV's per shift. After receiving and registration, the ELV's are inspected and then the car parts to be removed are determined.

The removal of the liquids is made in the area of pre-processing. The area is equipped with a drain-off station and with special drilling equipment for the removal of the fuels. The battery and the tyres are also removed in this area.

After the removal of the liquids the vehicles are transported to the storage for previously processed ELV's. The transport of the ELV's is made at the yard with a forklift truck.

The drained off vehicles are transported afterwards to one of the two dismantling stations. The dismantling is made according to the appropriate dismantling quantity. One of the dismantling stations is provided with a hydraulic ramp and with an engine tearing equipment. Both dismantling stations are provided with a crane and with the appropriate tools. Workbenches allow further dismantling of components. There are several containers for the collection of the dismantled car parts. After the dismantling activities, the dismantled parts are transported and stored outside the building in the container storage.

The remaining car wrecks are then transported to a press, where they are compacted or are placed in the storage for car wrecks for transport. When the storage is full, a truck equipped with a press comes to the yard and compacts the wrecks in order to gain more space on the truck.

The storage for car parts, as well as the shop for the car parts is in the building. Another important part of the system is the computerised management of the car parts. The monitoring and the registration of the ELV's are to be made with the help of dedicated software. The advantages of the dismantling yards are the high flexibility, also according to the specific gaining of car parts. The disadvantages are the low grade of automation as well as the greater space demand, which results from the containers needed at each station.

But the main advantage is the flexibility for processing ELV's. If a dismantler has invested during the last years according to the upgrade of the environmental standards, it would be no problem for him to meet new standards, including low costs, which is not the case of a dismantling line.

9.3 Products and materials of the dismantling of ELV's

The products and materials gained from the dismantling are destined to reuse, direct recycling or indirect recycling. The remaining materials, which can be neither recycled nor recovered, have to be disposed of. The advantage of the dismantling is, furthermore, a lower contamination of the car wreck delivered to shredder facilities, due to the removal of liquids and hazardous components. The car wreck still has other materials apart from steel.

9.4 Parts for reuse

Car parts with the greatest demand from clients and car garages are parts with a lot of wear, parts with damages due to accidents or rock falls and tuning equipment. The following parts and components are often reused:

- engine
- gearbox
- lighting dynamo
- starter
- fuel pump
- axles
- carburettor
- spray injection system
- radiator
- wings
- parts of the car body
- radio
- illumination, head lamps and rear lamps
- indicators
- glazing
- tyres
- tuning equipment
- bumpers

The sale of car parts is one of the main incomes of the dismantler. According to the information obtained from a dismantler, they have incomes between 100, - and 150, - DM per vehicle. According to the study *ARiV Automobil-Recycling im Verbund* the income is about 200, - DM per vehicle.

9.5 Steel and non-ferrous scrap

The material flux of steel scrap is the greatest flux in quantity in car recycling. The car bodies are normally pressed at the yard either by a fixed press or by a truck carrying a mobile press, in order to facilitate the transport and to increase the efficiency of the transport. The car bodies are afterwards delivered to the shredder facilities.

Nowadays the non-ferrous scrap is gained mainly in the shredder process, but there is a possibility of gaining aluminium, copper, zinc and lead from the dismantling of parts of the engine, of components, of the electric and of the rims. These materials could be recycled afterwards in foundry. The removal of the catalysts is today already standard because of the high value of the metals platinum and rhodium, which have a value of about 30 DM (source: ADA Autorecycling im Überblick) per catalyst.

9.6 Plastics and rubbers

In order to recycle plastics and rubbers directly, the plastics and rubbers have to be gained in the genuine form. But this is very difficult because of the great diversity in basis polymers, blends and compounds.

According to the German voluntary agreement, the car manufacturers need to take over their product responsibility and constantly want to optimise the construction for recycling, and the plastic producing industry wants to upgrade the recycling properties of their products.

A limitation to a certain number of employed plastics and rubbers could also help to facilitate the recycling of these materials.

At the moment, only a few plastic parts of an ELV are recycled, i.e. bumpers of PP or PC, hub caps of PP or PA, rear lights of ABS or PMMA, or the battery housing of PE. According to the information obtained from ARGE-Altauto almost every car manufacturer has already given the release for, for example 30 %, recycled plastics in invisible car parts, for example battery housings, painted bumpers or the wheel arch closure.

The non-recyclable products have to be recovered, i.e. incineration with energy recovery, incineration without energy recovery or, without other possibilities, landfill.

9.7 Liquids

Due to the complete removal and the genuine gain of all liquids of the vehicle, which are considered as a special waste, it is possible to re-process some of the liquids: the fuels can be reused by the staff of the dismantling yard; the oils can be incinerated with energy recovery and also as a support of incineration in special waste incineration plants or in waste incineration plants and they can be re-processed or they have to be disposed off as a special waste.

10 ANNEX II – SHREDDER TECHNOLOGIES

The typical mass flows obtained from shredding an ELV are as following:

- 69 mass-% of the Input is ferrous scrap
- 6 mass-% of the Input is the so-called heavy fraction of the automobile shredder residue (ASR), which consists mainly of non-ferrous metal scrap and some non-metallic materials
- 25 mass-% of the Input is the light fraction of the automobile shredder residue (ASR), which consists mainly of plastics, rubber, glass, dirt, paint and other low-density materials (source: Härdtle, G. et al, Altautoverwertung 1994)

Figure II.1 shows the mass flow of materials at shredder facilities according to Härdtle, G. et al, Altautoverwertung 1994.

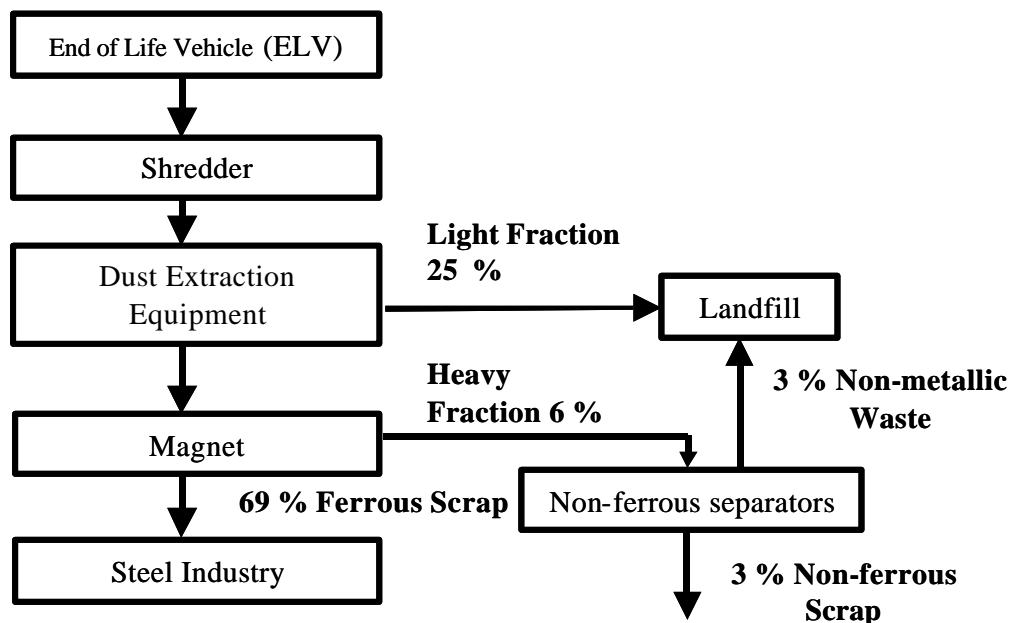


Figure II.1 – Mass flow of materials at shredder facilities.

The steel scrap separated with the magnetic drum consists of a purity of 98 mass-% with a specific bulk weight from 1,1 t/m³ to 2,5 t/m³. With these properties the steel scrap meets thus the requirements of the steel industry. The steel scrap can be, therefore, directly recycled in the steel industry. With the shredder process, around 96 mass-% of the steel contents of an ELV, can be gained regularly (Härdtle, G. et al, Altautoverwertung 1994).

A more difficult process is the separation of the heavy fraction of ASR, the mass flow, which remains from the magnetic separation. This mass flow consists of:

- 41,2 % aluminium
- 5,0 % copper
- 28,7 % zinc
- 1,8 % lead
- 23,3 % others (Härdtle, G. et al, Altautoverwertung 1994)

For the recycling of the heavy fraction of ASR a separation of metallic and non-metallic materials is needed. In general, currently only the metallic contents of this fraction are recycled in the Netherlands and in Germany.

While processing this fraction one has to distinguish between wet and dry processes.

The separation in the wet process, the so-called Swim-Sink-Process, is accomplished by regulating the density of the liquid. A preliminary separation of non-metallic materials is done while washing the fraction. Subsequently a magnetic separation of the still in the fraction containing ferrous metals is made. Afterwards, plastics, rubbers and magnesium contents are separated in an adequate regulated ferro-silicon-bath (iron and silicon dissolved in water) of about 2,0 kg/ l density. While the above named fractions swim up, the remaining non-ferrous metals sink down. After this separation step, the remaining non-ferrous metals are separated with a ferro-silicon-bath of 3,4 kg/l density,

bringing up the aluminium. The density of some materials involved in the swim-sink-process is shown in figure II.2.

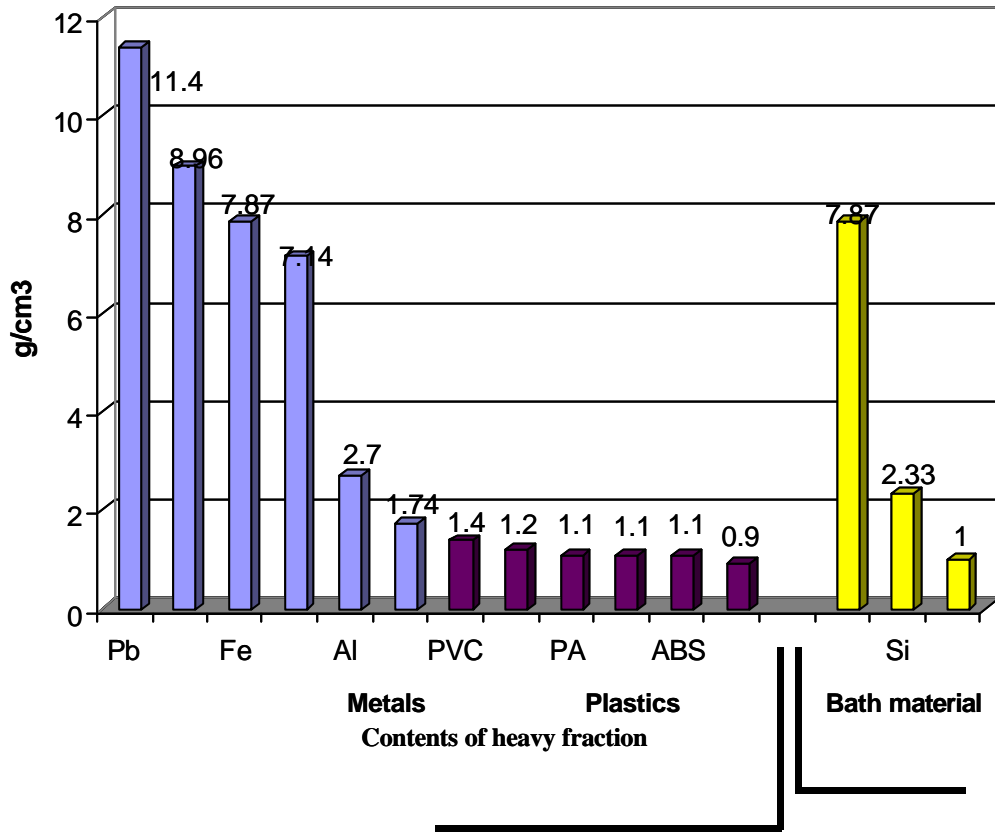


Figure II.2 – Materials density map

After each of the separation steps, the fractions are washed and the washing water is led back to the process. In spite of the washing procedure, an output of ferro-silicon-bath of 4 to 5 kg per ton input of the heavy fraction is not avoidable. This process requires an extensive wastewater treatment. The separation performance of the process is between 90 and 96 %. Due to the high costs of the process and due to the possible separation performance, the technical development is focused on the dry separation processes.

While processing the heavy fraction of ASR making use of a dry separation process can be made via an analytic identification, and that is not industrially available, or via the metal specific reaction on the inducement of eddy currents (eddy current separation process).

An analytic identification, for instance, can be made via the atom-emission-spectroscopy. A pulsed laser beam is emitted on the heavy fraction with a HeNe-Laser, which produces plasma on the surface of the material. The spectral lines emitted from the material due to this effect are then registered via detectors. The material is then identified due to electronic signal processing and a control command is given to the sorter of the machine according to the identification.

The eddy current separation process makes use of the different conductivity of metals. Time variable magnetic lines of force induce into the metal piece eddy currents. Each current flux results in magnetic lines of force, which opposes against the initial magnetic lines of force. Therefore an interaction between the magnetic lines of force is caused. The separation parameter is the quotient of electric conductivity and density of the material. There are two processes for the generation of time variable magnetic lines of force in use. In the first process, the magnetic lines of force are varied continuous or discontinuous, the quantity of the repulsive force is not dependent on the velocity of the metal piece. The second process is based on the motion of the metal pieces in a stationary magnetic field, the repulsive force depends on the velocity of the metal pieces. This separator is called ramp separator (based on Härdtle, G. et al).

In order to separate the heavy fraction exactly, the non-ferrous metal parts, which pass through the ramp separator, have to consist of approximately the same size. The scrap is therefore screened before the separation process in rotating screening drums into different sizes.

In the ramp separator only small metal parts, smaller than 3 mm, cannot be separated exactly. Only combined parts of different metals and non-metals have to be separated manually. The rest of the separation process is done automatically.

Each metal part of a certain material follows a certain curve and falls down into the provided container depending on the repulsive forces of the material.

A separation of the heavy fraction of ASR above described is normally only economically viable if the mass flows of several shredder plants are led together.

Another possibility, not technical advanced and accompanied with very high wage costs, is the manual separation of the heavy fraction of ASR. This is not a satisfactory work for the employees and needs a certain routine for the separation of the materials.

The light fraction of the automobile shredder residue (ASR) consists mainly of organic materials. The average contents are as following:

13 mass-% thermoplastics free of chlorine

6 mass-% PVC (polyvinyl chloride)

7 mass-% foams (polyurethane)

3 mass-% other thermoplastics and duroplastics

23 mass-% elastomeres (rubbers)

4 mass-% wood and cellulose materials

6 mass-% fibre and fabric materials

3 mass-% paint

13 mass-% glass and ceramics

13 mass-% iron

1 mass-% copper

3 mass-% aluminium

5 mass-% other contents (sand, dust, rust, lead, zinc, and others), (based on Härdtle, G. et al, *Altautoverwertung* 1994)

Currently, the recycling of the light fraction is not economically viable. For example in Germany, according to the technical regulations concerning waste processing (TA Abfall) the light fraction is considered as a waste requiring special control, which must be controlled while disposing off. If the recovery of the waste is not possible, the regulation considers the incineration in a special waste incineration plant as a mean of pre-treatment of the light fraction. If it is not possible (no incineration capacities) and if the content of PCB is under 10 mg/kg

and the content of hydrocarbons is under 5 mass-% the dispose off at landfill is allowed. In Germany there is a transition period until the year 2005, in which the light fraction still can go to landfill.

The thermal recovery of the light fraction was, until now, only tested on pilot scale (Mill-Fuel Process, direct incineration in cement kilns, out-gassing, high temperature gassing, low temperature pyrolysis with incineration of the pyrolysis gases in a cement kiln, fluidised bed combustion). Currently, only the thermal recovery, in addition to the landfill, consists a possibility for processing the light fraction of the ASR. This possibility must be developed in the near future, even when more parts and materials are going to be dismantled from an ELV.

The thermal recovery has the following aims:

- destruction of the organic contents
- volume reduction of the remaining material
- inertisation of the remaining material and anorganic harmful contents
- use of the calorific value or gain of synthesis gas
- recycling of the containing metals

The remaining solid materials from the incineration have to comply the regulations concerning waste processing, the gaseous emissions have to comply the regulations concerning emission protection. Special attention has to be paid to the avoidable emission of dioxins resulting from the incineration process and to the processing of the laden exhausts.

The tested thermal recovery processes for the light fraction are the pyrolysis in a rotary kiln, the pyrolysis in the fluidised bed, the smoulder combustion process, (the combustion in a rotary kiln or in a fluidised bed or the high temperature gassing). Pyrolysis and gassing can be distinguished from the combustion due to the production of a combustible gas, which can be used during the process or can be used externally in other processes.

The above named thermal recovery processes with the different concepts and incineration models have neither brought ecological nor economical success. According to information obtained from shredder facilities in Germany, the limit of economical viability for the costs of disposal of the light fraction is about 180 DM/ t. The costs of the thermal recovery processes are normally much higher than 300 DM/ t. Therefore there was an attempt to treat and separate the light fraction of the ASR, in order to get new mass flows which can be used in other applications. There are a few processes, which make use of these separation techniques. Normally there is an attempt to get a ferrous fraction, a non-ferrous metallic fraction, an inert fraction and a fraction with a high calorific value.

The so-called *WESA-SLF-Verfahren* is a dry-mechanic separation process, whose aim is the complete separation of the organic and inorganic contents of the light fraction of the ASR. The separation criteria are the density of the contenting materials, which allow a sufficient separation between the organic and anorganic matter. To guarantee the full separation, the light fraction, including wire, has to be shredded until a certain amount so that the insulation of the copper wire is fully removed. This aim is reached by shredding the light fraction inferior to a grain size of 7 mm. A flow diagram of the WESA-SLF-Process is shown in figure II.3.

The shredding of the material is made in a two-step-fragmentation. Before fragmentation the material is screened, in order to achieve a grain size inferior to 6 mm. The first step of fragmentation is made in a so-called rotor-shearing machine inferior to a size of grain of 20 mm. Downstream a magnetic separation is made in order to protect the subsequently following main fragmentation with a so-called one-shaft-shear-shredder. The required size of grain of less than 7 mm is obtained with an included screen.

Because of the varying moisture content of the material, which can vary between 5 and 25 % according to the season, the origin, and the difficulties while screening moist material, the whole light fraction has to be dried at a moisture

inferior to 2 %, after the two-step-fragmentation in a belt conveyor oven. Another difficulty are the agglomerations between moist organic and inorganic material.

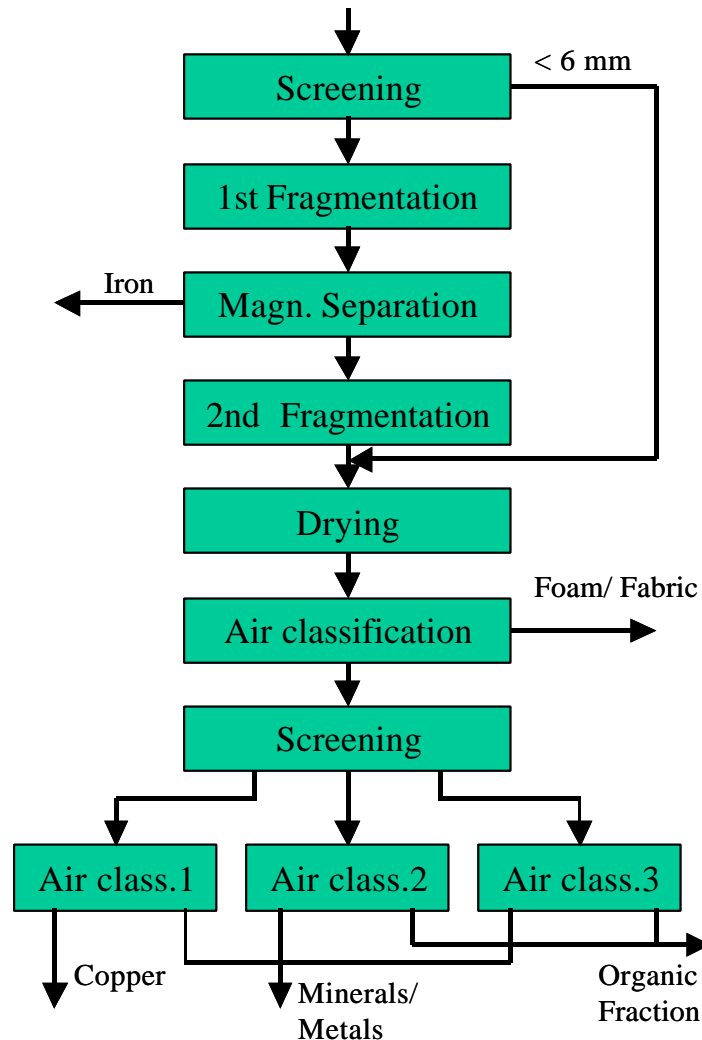


Figure II.3 - Flow diagram of the WESA-SLF-Process

The dry process is done after shredding because the surface of the light fraction is then larger and therefore the dry process is more effective. Due to experiences made with subsequent interlocking of, for instance, copper wire and foam, subsequently after the dry process, a first air classification is made with a zig-zag air classifier.

This type of air classifier is a flow separator, which consists of a vertical channel in a zig-zag form. The calculated classifier stream flows upwards to the classifier, the feeding is done above the centre of the classifier via a rotary feeder.

Particles with a sinking velocity above the critical sinking velocity cannot follow the flow and sink down to the output of the heavy material at the bottom of the classifier. The particles with a sinking velocity below the critical sinking velocity are carried over with the classifying air flow and are separated at a switched on cyclone separator. This light material is discharged via rotary feeders at the bottom of the cyclone. Thus, the foam and fabric particles are taken from the mass flow while doing the first air classification.

The heavy material from the bottom of the classifier is then screened into three fractions of different size of grains. This separation is necessary in order to separate the heavy material with other zig-zag air classifiers in a high selectivity.

After the separation process the following fractions are gained:

- a ferrous fraction with approximately 95 mass-% iron
- chopped copper
- a mixture of metals and mineral materials
- the organic fraction, with the elementary contents and calorific properties according to the experiences made so far:
 - metal, each less than 0,5 mass-%
 - carbon 50 mass-%
 - hydrogen 6 mass-%
 - oxygen 12 mass-%
 - chlorine 1 – 2,5 mass-%
 - ash 20 – 28 mass-%
 - calorific value > 23 MJ/kg

The gained ferrous scrap and the copper are delivered to foundries and to the steel industry. The mixture of metals and mineral materials can be used as filling material in mining and construction applications. With these two fractions a profit can be made.

The organic fraction can be used due to its high carbon content and high calorific value thermal in gasification plants, in combined heat and power stations, or to recycle the material as a supplier of carbon in a blast furnace. The applications could be possible in a rotary kiln, in a fluidised bed, in the blast furnace or in a cupola. The project is still in pilot scale but much emphasis is given in Germany to this process. The investment for such a plant is about 4 million DM and the process costs are estimated between 120 and 150 DM/t. The turnover is calculated with 4 t/h, respectively 16.000 t/ year (250 working days per year and two-shift working).

The main environmental burden is caused currently, while processing ELV's, by the light fraction of the ASR (25 mass-% of the Input), which has a hazardous waste character due to the fluids that still remain in the ELV while shredding and due to the processing of mixed and collected scrap at the same time.

Although the amount of the light fraction of the ASR in comparison to the entire amount of domestic waste and domestic similar waste is only about 1,5 %, the disposal of the light fraction is increasingly more problematic.

In 1991, the German Federal Environmental Agency (Umweltbundesamt UBA) has carried out a study concerning the light fraction of ASR. In the study, the light fraction off processed ELV's, which were not drained off, mixed with light collected scrap contained more than 150 mg/kg of polychlorinated biphenyl (PCB). The shredding of completely drained off, but not dismantled ELV's, without any collected scrap, contained less than 10 mg/kg PCB. A further dismantling of the ELV's did not lead to a decrease of the PCB content in the light fraction (based on Härdtle, G. et al, Altautoverwertung 1994).

It can thus be concluded that the contamination is caused by the in the ELV remaining fluids, for example motor and gearbox oil, as well as by the added light

collected scrap. For the light collected scrap this conclusion was confirmed while separate shredding, the PCB contents of the light fraction were more than 200 mg/kg (based on Härdtle, G. et al, Altautoverwertung 1994).

It is scientifically proved that polychlorinated biphenyl (PCB) is carcinogen. Another problem is the formation of polycyclic aromatic hydrocarbons in motor oils while running the car because of thermal reactions. It is also proved in animal testing that these hydrocarbons are carcinogen. The danger comes from the polychlorinated biphenyl and from the polycyclic aromatic hydrocarbons to the respiratory organs and to the digestive organs.

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