

THE UNIVERSITY OF CHICAGO

DEPARTMENT OF CHEMISTRY

PHYSICAL CHEMISTRY

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## END OF LIFE VEHICLES RECOVERY: PROCESS DESCRIPTION, ITS IMPACT AND DIRECTION OF RESEARCH

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### ABSTRACT

*In recent years, environmental issues and sustainability have become one of the main items of debate in the automotive industries. In relation to that, most countries have set a new legislation because the situation is getting worse especially in the developed country. The legislation forces all the vehicle manufacturers to accept responsibility for the complete life cycle of vehicles. In another words, the vehicle manufacturers are forced by law to take back and recycle their products in order to support product stewardship and to enforce environmentally friendly product life cycles. This paper provides a snapshot of current practices in vehicle recovery in Europe, USA, Japan and Australia together with legislation, stakeholders and markets influencing in industry. The concepts of sustainable development and end-of-life vehicle recovery are discussed. The paper then outlines the factors that must instigate the longer-term changes required to more readily support the core themes of the end-of-life vehicle recovery.*

**Key Words:** *Vehicle Recovery, End-of-Life Vehicle Directive, Vehicle Design and Development Process, Vehicle Industries, Recycling Aspects*

### 1.0 INTRODUCTION

The concept of sustainable development is not easy to define and explain because the definition depends on the context in which the concept is used. Jonsson (1996) believes that the available knowledge at a certain time affects the way sustainable development is defined. Generally its can be defined as a development that meets the needs of the present generations to meet their own needs. There are several issues that have to be considered in developing the sustainable concept. According to the Brundtland Report, sustainable development should be focussed on minimal

use of non-renewable resources, minimal emission of pollutants and protection of the fauna and the flora of the earth (Welford, 1995).

Based on that, with the rapid development of the sustainable concept, recycling industries have become more popular. In relation to this, automotive recyclers have been leaders since the early days of the development of the vehicle. They have played a major role in the ecological disposal of end of life vehicles (ELVs), primarily because of the financial benefits involved. Besides the reclaiming of reusable components through the recycling of ELVs, the need for landfill is reduced.

As an example, in the European Countries (EU), automotive recycling started to become established when abandoned vehicles were beginning to cause major problems. This happened in the 1960s (Sorge, 1994). This problem was solved considerably when the crusher machine was developed. The function of this machine is to crush the hulk of a vehicle to enable the metal content to be recovered. The other components such as plastic and other non metallic parts were burnt out.

Because of the increasing number of vehicles on the road, used spare parts were becoming increasingly popular. According to Johnson (2002), every year in the EU, some 15 million vehicles reach the end of their useful life. Some die prematurely due to accidents but some expire from old age, when they fail to pass inspection or require uneconomic repair. In 1960s, entrepreneurs began to set up automotive recycling businesses because it was seen as value for money (Field, 1994). At the beginning, these were mainly small family businesses. In this process, the first step was to remove the useful parts from the vehicle. Once these were removed, the interior was burned out and the hulk was either crushed on site or sold to a scrap metal merchant to be crushed. The crushed steel hulks were sold to the steel industry to be recycled. The other materials such as copper, lead and aluminium were removed from the vehicle and sold for recycling.

When the several legislative acts such as clean air, environment etc. were introduced, these led to the development of shredding process. According to Wright et al. (1998), the first shredder operated in the United Kingdom (UK) in the 1970s. The material from the shredder travels through a series of magnetic and air separators using a conveyor system. The shredder scrap is separated into three fractions ferrous metals (steel and cast iron), nonferrous metals (aluminium, copper, lead etc.) and non metallic (plastics, fluid, glass, dirt and other contaminants known as Automotive Shredder Residue-ASR). Currently, with the introduction of the Directive on ELVs, several recycling companies have grown considerably.

In the future, automotive Original Equipment Manufactures (OEMs) may revolutionise the recycling industry to a new level by entering the recycling business. This would be a sensible method of achieving environmental and economic goals for vehicle manufacturers. They can control the supply of recycled materials, reduce material costs, improve shareholder value and enable their vehicles to be sold at a competitive price.

## 2.0 ELEMENTS OF DESIGN FOR RECYCLING FOR ELVs

As vehicle manufacturers are expected to recycle ELVs at their own costs, the type of materials chosen is a key element in the vehicle development process. The choice of materials is of great significance with a view to problem materials and their direct reuse as materials for subsequent processes.

The composition of a typical vehicle has changed substantially in recent years. For example, ferrous metal content has decreased significantly but more plastic materials are incorporated because they are lighter and more fuel efficient. Passenger vehicles are an outstanding example of complex multi component consumer products. The average vehicle is assembled from about 10000 parts of which there are a large number of different materials. An analysis of vehicle manufacturer data for around seventy popular vehicle models shows the material breakdown (by weight) of an average passenger vehicle as shown in Table 1.

Table 1: Material breakdown of an average passenger vehicle  
(ACCORD Annual Report, 2001)

Material Breakdown	Average Weight (kg)	% of Weight
Ferrous Metal	776.6	68.0
Plastic	102.8	9.0
Non-Ferrous Metals	91.4	8.0
Glass	34.3	3.0
Tyres	34.3	3.0
Fluids	22.8	2.0
Rubber	22.8	2.0
Electrical Parts	11.4	1.0
Process polymers	11.4	1.0
Carpets	11.4	1.0
Battery	11.4	1.0
Other	11.4	1.0
Total	1142	100

Generally, the majority of materials used are capable of being recycled but some are better than the others for various reasons like quality, demand, reprocessing cost and durability. Table 2 shows an example of parts being recycled from ELVs.

In relation to this, over recent years the environment has become a core strategic planning issue in the world. Design for Recycling (DFR) or Design for Environment (DFE) plays a main role in the vehicle development process. It considers all the recycling aspects and also environmental factors during the design stage of a vehicle to increase its recyclability at its end of life. Wider application of DFR or DFE would involve improving the logistics networks for the recycling infrastructure and establishing stable markets for the recycled materials.

Table 2: Parts recycled from ELVs (Toyota, 2005)

Part	Recycled	Part	Recycled
1. Window (glass)	Tiles etc.	2. Seat (foam and fiber)	Soundproofing materials for vehicles
3. Body, trunk, hood and door (steel)	Car parts and general steel products	4. Wire harness (copper)	Copper and engines products (cast aluminium reinforcement)
5. Bumper (resin)	Bumper, interior parts, toolbox etc.	6. Radiators (copper and aluminium)	Gun metal ingots and aluminium products
7. Coolant, Engine and gear oil (oil)	Alternative fuel for boilers and incinerators	8. Engine, transmission, suspension and wheel (steel and aluminium)	General steel and aluminium products
9. Catalytic converter (rare metals)	Catalytic converters	10. Tyre (rubber)	Raw material and alternative fuel for cement manufacture

Basically, there are two main factors that influence the DFR or DFE concept in automotive engineering; disassembly and recycling. In order to successfully implement this concept, several parameters have to be considered in developing a new passenger vehicle such as selection of material, method of joining and also the characteristics of the components' design. In the early 1990's, the BMW Group's Recycling and Dismantling Centre developed a recycling manual as a guide for the DFR and DFE concept (BMW Group, 2000). This manual provides a guideline to design a vehicle to fulfil the environmental criteria and recycling requirements. These guidelines are broken down into three main areas; methods of joining and fixing, selection of materials and design of components.

### 3.0 RECYCLING TECHNOLOGY

According to Altschuller (1997), recycling implies that material is processed out of one form and remade into a new product. Basically, the current recycling or processing of ELVs can be divided into two processes; dismantling and shredding. The dismantling process can have higher recycle value of the component and it allows the product to be reused or reconditioned. Meanwhile, in the shredding process, an ELV is compressed and fed into a drum, where it is ripped apart by a set of rotating hammers until it is sufficiently small to drop out of an output grid where light materials (such as plastics etc.) are separated from heavy materials (such as steels etc.). However, the efficiency of both processes depends on the characteristics of the design applied in the designing process. Therefore, to make the recycling concept more successful, the hierarchies of the recycling process must be considered in the early stage of the design process. This hierarchy can be divided into four components; reuse, recycle, recovery and waste as shown in Figure 1. It shows that reuse of a component is the first priority in the product

design processes. If it cannot be reused directly, it might need some additional work on the same form/pattern or to make into another form/pattern. This is called remanufacture or reconditioning. The second tier in this hierarchy is recycling. Recycling can be defined as the processing of component to produce a raw material. This can be divided into two categories; high grade material and low grade material. The next process that must be considered is a recovery. Recovery is the use of waste for useful purposes such as energy recovery, road surfacing etc. Then, the last consideration is a waste material that is sent for disposal in landfill.

ELVs can be categorised into 2 main groups; natural and premature. Premature vehicles have come to the end of their useful life before their average lifespan, either due to fire, theft, flood, vandalism or accident damage. These cases often have a wealth of reusable part removed before further processing. Meanwhile, natural ELVs are vehicles that reach the end of their useful life. It tends to be in a bad state of repair and part resale value is at a minimum and often a number a health and safety issues need to be addressed before de-pollution and further processing.

Basically, de-pollution processes begin with removal of the battery, fluids, tyres and any other hazardous substances. High value components are then removed via manual disassembly which has also seen a number of smaller facilities separate pure stream plastics to sell directly to the recyclers and re-processors. Then, the rest of the body is crushed and transported to shredding operations for post-fragmentation recovery. Once the ferrous content has been recovered, the non-ferrous scrap can be separated using Dense Media separation processes and the remaining waste is sent to landfill. The summary of the recovery processes is shown in Figure 2.

Based on this, it can be concluded that there are several key elements in managing the recovery of ELVs; dismantling facilities, shredding facilities, automotive shredder residue (ASR) and landfill.

### **3.1 Dismantling**

The dismantling industry has a big potential in the future especially when the EU Directive on ELVs is fully implemented. Dismantling is very limited at present because it is labour intensive and uneconomical. A few high value components are stripped off the vehicle before it is sent to the shredding process. Dismantling company can be categorised into two types of businesses, there are high value parts business (a business that removes and inventories useful and high value parts for resale) and scrap yards business (store the ELVs while the parts are gradually removed and sold to local repair shops and do it yourself (DIY) owners).

### **3.2 Shredding**

This is another process for disposal of ELVs. The shredding industries are capable of processing a large quantity of ELVs with capital intensive sites. The main output from this process is a ferrous metal, which is sent to steel industry for recycling (Aboussouan et al., 1999). Currently, most of the ASR is sent to landfill for disposal. Reduction of this waste stream through the recovery and recycling of plastics is the focus of other current research (Ambrose, 2000).

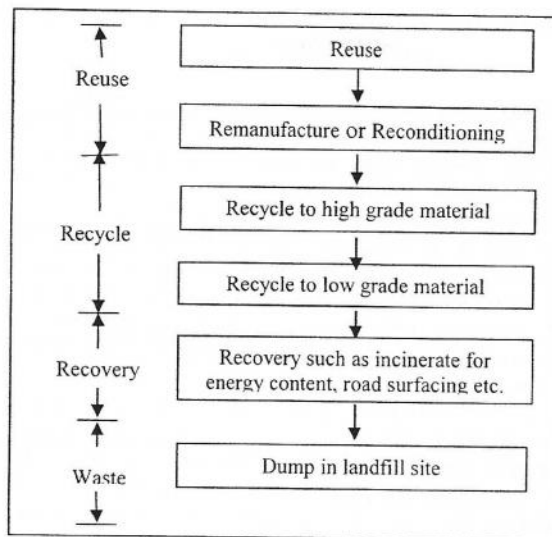


Figure 1: The hierarchies of recycling (Simon, 1991)

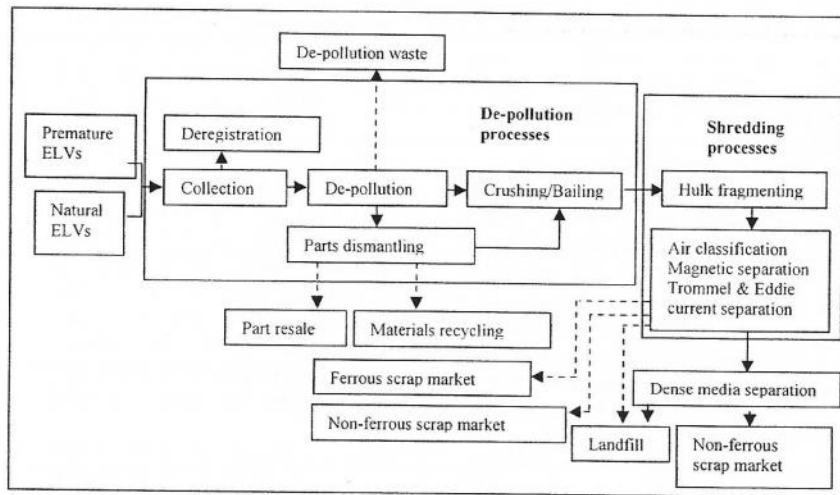


Figure 2: Current vehicle recovery infrastructure (Edwards et al., 2005)

## **4.0 LEGISLATION IMPLICATION**

### **4.1 EU Proposal**

Currently, most of the developed countries have set new legislation, which is planned to force vehicle manufacturers to recover and recycle their products at the end of their life. A new directive for EU countries which became effective in April 2002 compels governments to enforce the responsible disposal of vehicles that have come to the end of their life. According to the UK Department for Environment, Food and Rural Affairs (DEFRA), 300 000 vehicles are already simply abandoned by their owners every year in the UK and between 8 and 9 million tonnes of waste are generated from ELV's within the EU (Chatterley, 2002). Of that, 75% is ferrous metal, which is recycled through traditional metal dealers to produce new steel or other ferrous products and 25% goes to landfill sites to become waste.

Although it is a few years away from being fully implemented, the EU Directive on ELVs is already weighing heavily on the mind of most vehicle manufacturers in Europe. The first stage was introduced on 18 September 2000 to reduce the proportion of ELVs content going to landfill and then a second stage in October 2002. There are up to 10 million vehicles a year in the EU reach the ends of their first useful life.

In response to this, the German and Dutch authorities introduced the concept of 'Producer Responsibility', which obliges the car manufacturers to take back ELVs. This is to control the disposal of ELVs (King et al., 2005). The vehicle manufacturers decide to reduce the environment burden from their products by improving the recyclability of vehicles. However, when the EU Directive stated that they must take back and treat ELVs at no cost to the last owner it generated intense opposition from the manufacturers, as they would have to assume a great financial cost.

Following the identification of ELVs as a priority waste stream by the EU in 1989, a directive was first drafted in 1997 which set quantitative targets for the recovery, reuse and recycling and a free take back procedure for vehicle manufacturers. A common position was reached in 1999 after several key points of the original directive were adapted and the Directive finally came into force in October 2000. The main provisions cover aspects such as promotion of awareness, requirements related to depollution and dismantling of ELVs and the reuse, recycling and recovery of materials from ELVs, setting up of collection network, outlining quantitative targets for recovery and recycling until 2015 and demanding member states to make laws, regulations and (enforceable) agreements by April 2002 (Glass and Pascoe, 2002).

The introduction of the directive will affect all players involved in the management of ELVs in terms operational strategy, infrastructure and financial investment. The whole structure of automotive recycling is expected to change. The traditional dismantling techniques will become more advanced, as legislation demands the removal of all hazardous liquids and components. Some form of plastics, rubber and glass recovery is necessary, either during the dismantling phase or during the separation process.



The directive has resulted in major investment in research and development, especially in areas of recyclability and investigation into new techniques and technology for disassembly and recycling.

#### **4.2 United State of America (USA)**

In the USA, there is no specific legislation regarding the management of ELVs. All materials, either waste materials or recycled materials, are considered as a solid waste. So the recycling industry has received much less interest. Currently, there is no shortage in waste disposal sites because of abundant land. This situation can make the costs of waste disposal low. Furthermore, there is no standard waste legislation for the whole of the US. Every state has its own legislation, so the target and implementation varies from state to state.

However, Ford, Daimler Chrysler and General Motors have provided a special programme to study how to improve recyclability rate and methods to decrease the current ASR burden. Most of the recycling industries in the US belong to the automotive industry. Ford has purchased more than 25 vehicle recycling operations in the US, with more expected and has an experimental dismantling center in Germany (Staudinger and Keoleian, 2001). The USA Environmental Protection Agency (EPA) is trying to promote the recycling concept among the vehicle manufacturers (EPA, 1997).

#### **4.3 Japan**

Most of the vehicle manufacturers in Japan are branching out into the recycling business and developing easy to recycle vehicles in response to a new automotive recycling law that is implemented in 2004 (Recycling Based Society Law, 2004). The first legislation was introduced in 1990 that promoted the use of recycled resources, applying particularly to automotive industries. Then in 1996 quantified targets for recycling ELVs was set at 85% by 2002 and 95% by 2015 (Recycling Initiative, 2005). As in Europe, Japan has considered the issue of recycling of ELVs to be a priority area.

According to the Japan Automobile Manufacturing Association (JAMA), the waste disposal law specifies that shredder residue is a waste that requires specially controlled landfills. There are few of these landfills that meet the strict standards, which have led to an increase in the cost of landfilling. Although this is the case, about 50% of ELVs are still traded at a profit due to the value in metals offsetting the cost of landfilling with the waste (JAMA Report, 2004).

#### **4.4 Australia**

In Australia, there is no legislation that requires the last owner of an ELV to enter the recycling infrastructure. Also, the last owner of a vehicle does not need to deregister it. Currently, new requirements for ELVs are being introduced in all local councils. Those requirements will give full authority to local councils to take action for the ELVs even though they are stored on private property if they are causing a health or fire hazard or a loss of amenity to other residents.

In relation to that, some states such as Western Australia have highlighted abandoned vehicles as being of broader concern. It will cost the local authorities to store abandoned vehicles for some weeks before disposing of them. In order to

reduce the cost, some of the local councils have introduced collection points for ELVs. It seems likely that the proportion of ELVs reaching recycling facilities is over 90% (Environmental Australia, 2002).

### 5.0 RESEARCH DIRECTION

The proposed research framework for ELVs recovery concept is a conceptual approach which is integrating recyclability concern at an early product design phase as shown in Figure 3. This approach is intended to provide an organized process that allows designers to identify and understand the recyclability needs and how to measure recyclability during the design process.

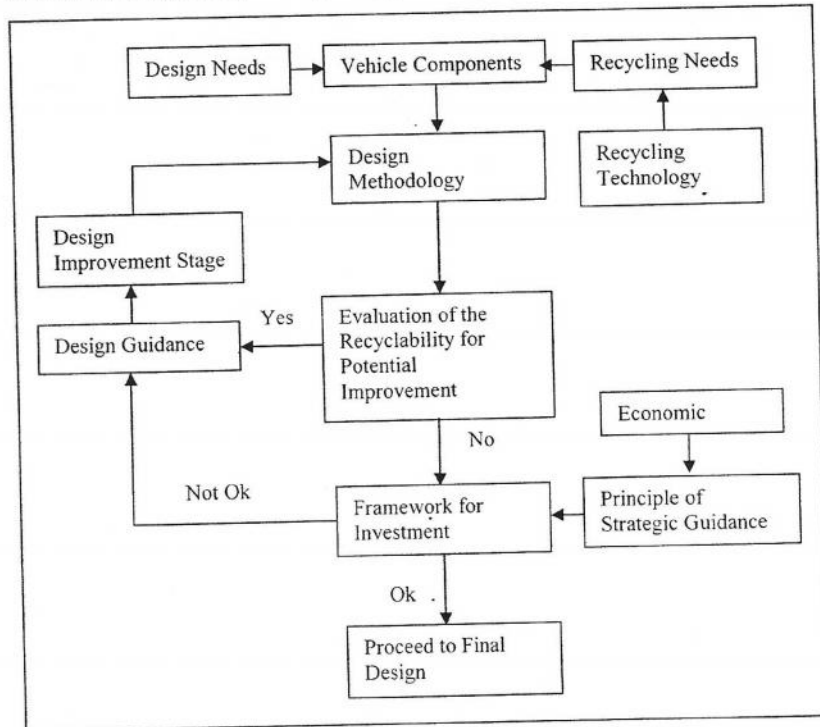


Figure 3: Research framework for ELVs recovery concept

Referring to Figure 3 there are three major areas that have been identified which influence the development of ELVs recovery concept. These are,

*i. Design methodology*

It clearly shows that there are needs for the methodology to be applied at the early stage of design process. In fact, it is essential for the vehicle designers to

incorporate recycling from the development stage in producing a new vehicle. The automotive industry has to give a full commitment to producing an environmentally friendly vehicle even if it will mean an increase in manufacturing costs. Based on this, the automotive industries have to change the traditional paradigm into a new paradigm in the product development process as outlined in Figure 4.

*ii. Economic aspect*

The long term economic benefits of products DFR can be assessed by total life cycle cost. These benefits are represented by the higher post-purchase value, which might have been hidden by a higher pre-purchase cost. Pre-purchase cost is given by material, manufacture and assembly costs. Meanwhile, post-purchase value can be obtained by subtracting all recycling costs.

Besides that, design changes are a major problem in this issue especially in order to cope with the ELV's requirements. Basically, design is the key to ensure that product will fulfil the fixed requirements such as customer needs, specification, cost and quality in every stage of a product's life cycle. In this case, ELV requirements need to be properly considered at the early stage of vehicle design to ensure that recycling is profitable. It would be a simple task to reach 85% to 95% recyclable or recovered material from the current design of vehicle but the situation now is that it is not economical. To recycle plastics and fluids the infrastructure must be in place to achieve the economies of scale needed to compete with virgin materials on cost (environmental and monetary). The environment will not benefit if more resources are used to recycle than when using virgin materials.

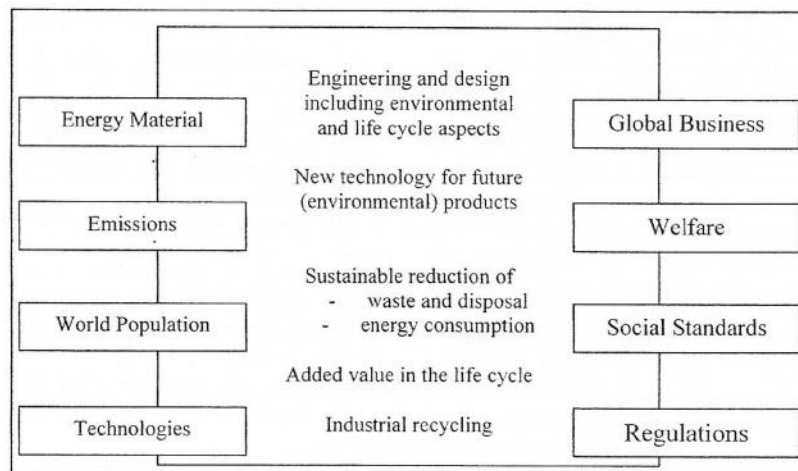


Figure 4: New paradigm for product development process (Westkamper et al., 2001)

*iii. Recycling technology*

Another fundamental problem involves the method with which the recovery target will be met. This could either be through an increased efficiency in recovering materials post-shredder or through the increased dismantling of part pre-shredder. Besides that, vehicle disassembly and recycling were became to be of high ecological and economic important. To comply with the increasingly tightening vehicle recycling legislation and to make the vehicle recycling business economically competitive, the process has to be automated to the highest possible extent.

## **6.0 CONCLUSION**

Based on the current situation, it will be possible to meet the Directive on ELVs reuse, recycling and recovery targets by 2006 with the existing organisational systems; however, the Directive sets more ambitious targets for 2015. The technology is insufficient and uneconomical at present. Meeting this target is likely to require significant costs and research and development in areas such as design concept, technology, automotive shredder residue and restructuring of infrastructure.

The basic problem with recycling ELVs is that the vehicles were not designed to be recycled. This reflects back on the vehicle manufacturers and it seems unreasonable that they will have to pay for disposal when the vehicles on the road today were not fully designed for recycling.

Overcoming the challenges to improve the recyclability of end of life vehicles will require a carefully planned strategy with full dedication from the key players involved in ELVs management. A monitoring system must be developed to track the Directive's progress. The actors involved must come together to share the cost of the development of new technology and to promote recycling infrastructure development. Vehicle manufacturers must continue to incorporate reuse, remanufacturing and recycling into the design of new vehicles. Uses for recovered materials must be developed. Investment in infrastructure and building on existing infrastructure is essential to achieve the recyclability goal.

Emphasis on research and development on ASR material identification, sorting and product recovery will have a significant impact on raising the market value of ASR and help avoid landfilling and incineration. It is therefore necessary to develop technology to recover materials from ASR. Dismantling is labour intensive so improving its efficiency will help make material and component recovery more economical. Therefore, increased materials recovery such as plastic, tyres and glass by better separation processes must be properly investigated especially in terms of market for those particular materials because every development process involves a lot of money.

It can be concluded that several elements in the vehicle development process need to be further developed especially in the early stage of the process in order to increase the efficiency of the recycling process.

## REFERENCES

1. Aboussouan, L., Russo, P., Pons, M. N., Thomas, D., Birat, J. P. and Leclerc, D. (1999) "Steel Scrap Fragmentation by Shredders", *Power Technology* 105, USA
2. Ambrose, C.A. (2000) "Post-Consumer Automotive Waste Arising, Disposal and Legislation", IWM Article November, Waste and Energy Research Group, School of the Environment, University of Brighton, UK
3. ACCORD Annual Report (2001) "End of Life Vehicle and Tyre Recycling Information Sheet", [Website]  
URL: <http://www.wasteonline.org.uk/resources/InformationSheets/vehicle.htm>  
[Downloaded on 15<sup>th</sup> April 2005]
4. Altschuller, A. (1997) "Automotive Recycling Alternatives: Why Not? - A Look at the Possibilities for Greener Car Recycling", Neighbourhood Planning for Community Revitalisation (NPCR), Internal Report, USA
5. BMW Group (2000) "Manual for Recycling - Optimised Product Development", Internal Document, BMW Group, Germany
6. Chatterley, T. (2002) "End-of-Life Vehicle Directive - Implication for Everyone...", MIRA - New Technology, Internal Report, UK, pp. 124-126
7. Edwards, C., Coates, G., Rahimifard, S., Bhamra, T., Newman, S. T. and Leaney, P. (2005) "End-of-Life Recovery of Vehicles in the UK", *Proceedings of the 4<sup>th</sup> International Conference on Design and Manufacture for Sustainable Development 2005*, UK
8. Environmental Australia (2002) "Environmental Impact of End-of-Life Vehicles: An Information Paper", [Website]  
URL: <http://www.deh.gov.au/settlements/publications/waste/elv/impact-2002/chapter5.html>  
[Downloaded on 26<sup>th</sup> June 2005]
9. EPA (1997) "Recycling Plastic Fractions", Environmental Protection Agency (EPA) Publication, USA
10. Field, F. R. (1994) "The Recycling of Automobiles: Conflicting Environmental Objectives in a Competitive Marketplace", Automobile Recycling Policy: Findings and Recommendations, International Motor Vehicle Program, Centre for Technology, Policy and Industrial development, Davos, Switzerland
11. Glass, H. J. and Pascoe, R. D. (2002) "Revenue from Residue", *ELV 2002 - End-of-Life Vehicles Conference*, International Manufacturing Centre, University of Warwick, UK
12. JAMA Report (2004) "Global Industry Get-together on Car Recycling", [Website]  
URL: <http://www.jama-english.jp/europe/news/2004/may-jun/topic1.html>  
[Downloaded on 7<sup>th</sup> June 2005]
13. Johnson, E. (2002) "Automobile Dismantling in Europe: Trends and Economics", *ELV 2002 - End-of-Life Vehicles Conference*, International Manufacturing Centre, University of Warwick, UK
14. Jonsson, G. (1996) "LCA: A Tool for Measuring Environmental Performance", Rexam Digital Imaging, UK
15. King, A., Miemczyk, J. and Bufton, D. (2005) "Photocopier Remanufacturing

- at Xerox UK: a Description of the Process and Lessons for other Industries”, *Proceedings of the 4<sup>th</sup> International Conference on Design and Manufacture for Sustainable Development 2005, UK*
16. Recycling Based Society Law (2004), [Website]  
URL: [http://www.chinacp.com/eng/cpcasestudies/ce\\_japan.html](http://www.chinacp.com/eng/cpcasestudies/ce_japan.html)  
[Downloaded on 7<sup>th</sup> June 2005]
  17. Recycling Initiative (2005) “Preparing for the Automobile Recycling Law”, [Website]  
URL: <http://www.toyota.co.jp/en/environment/recycle/law/outline.html>  
[Downloaded on 7<sup>th</sup> June 2005]
  18. Simon, M. (1991) “*Design for Dismantling*”, Professional Engineering, UK
  19. Sorge, M. (1994) “*Recycling an Old Idea: Auto Industry Working to Find Second Lives for Cars and Parts*”, Ward’s Auto World, USA
  20. Toyota (2005) “Recycling Initiatives”, [Website]  
URL: [http://www.toyota.co.jp/en/environment/recycle/nitty\\_gritty/](http://www.toyota.co.jp/en/environment/recycle/nitty_gritty/) [Accessed on 7<sup>th</sup> May 2005]
  21. Welford, R. (1995) “*Environmental Strategy and Sustainable Development*”, Biddles Ltd., UK
  22. Westkampter, E., Alting, L. and Arndt, G. (2001) “Life Cycle Management and Assessment: Approaches and Vision Towards Sustainable Manufacturing”, *Journal of Engineering Manufacture*, Vol. 215 No. B5, pp. 599-626
  23. Wright, C., Lewis, A., Hunston, H. and Bursa, M. (1998) “*Automotive Recycling Cost or Opportunity?*”, Financial Times Publishing, UK