Recycling Systems and Management of End-of-Life Vehicles (ELVs)

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October 23, 2007

A Center for Sustainable Engineering Education Module
SUMMARY

For many years the automotive industry has been taking environmental issues into account for the complete life cycle of their vehicles. From design to use to disposal, vehicles have a wide variety of effects on the environment. For the future sustainability of the automotive industry, one of the most important environmental challenges that must be addressed is the recycling of End-of-Life Vehicles (ELVs). As the importance of recycling ELVs grows, many automotive companies are developing new technologies for properly processing waste oils and liquids, as well as systems for recycling parts and materials in an effort to reduce ASR (Auto Shredder Residue) and reduce negative environmental impacts.

Currently about 10 to 14 million ELVs enter to the disposal system annually in the United States. As the number of vehicle registrations increase, the number of ELVs will increase significantly. Now approximately 75% of the total weight of each vehicle is recovered, and in terms of metal recovery, and over 90% of the metal. In order to protect the environment, ELV components must be routed away from landfills in favor of collection, reuse, and recycling programs. In order achieve this goal, policy and regulation must encourage the creation of total ELV management systems via extended producer responsibility and recycling target (already the case of Europe for instance) legislation.

This module focuses on recycling processes and technologies related to ELVs. This module also discusses the issues surrounding the existing scrap recycling system, vehicle recycling regulation, and management and policy in the United States, EU, Japan, and South Korea.

The target audiences of this module are advanced undergraduate engineering classes and graduate classes in sustainable engineering and industrial ecology. This module is part of a series designed for the Center for Sustainable Engineering (CSE). Instructor guides and further information are available at the Center’s website (www.csengin.org).

Keywords: End-of-life Vehicles (ELVs), Recycling System and Management, Sustainability, Dismantling and Shredding, automotive technology, sustainable mobility.
1. Introduction

The automobile is already one of the most effectively recovered and recycled consumer products in the United States and worldwide. Each year, approximately 94% of the cars and trucks we drive in the United States enter the vehicle recycling infrastructure when they reach the end of their useful lives. There are about 10 to 14 million End-of-life Vehicles (ELVs) generated every year in the United States (USCAR, 1998). Table 1 shows detailed information on ELVs in the United States. There are two main categories of ELVs. The first consists of relatively new cars taken off the road due to total loss accidents; these are known as premature ELVs. The second category consists of ELVs that have reached the end of their life naturally. Estimated median natural lifetime of vehicles is about 11-14 years for autos and 15-16 years for light trucks. (TEBD, 2000)

In the United States, there are approximately 6,000 to 7,000 dismantlers. About 80% of these dismantling facilities are traditional salvage/scrap yards. These low-tech operations collect most vehicles and store the ELVs as they slowly remove and sell reusable parts. The other 20% are high-value parts dismantlers that run a cost-effective operation on a high volume, quick turnover basis. The number of shredding facilities is much less, numbering about 200 in North America (Staudinger and Keoleian, 2001)

The auto recycling industry generates approximately $8 billion in sales per year in the United States. Automotive manufacturers are attempting to reduce the environmental impacts of the entire life cycle of their vehicles. Specifically, the manufacturers are attempting to improve the recyclability of their vehicles and thereby reduce the percentage of each car that must be disposed of in a landfill. ELVs are a major source of scrap metal.

One of the main purposes of this module is to introduce the current status of ELV policy and regulation in the United States, European Union (EU), Japan, and South Korea. This module also presents typical ELVs

<table>
<thead>
<tr>
<th>Year</th>
<th>Total vehicles in use</th>
<th>New-vehicle registrations</th>
<th>Used-vehicle registrations</th>
<th>ELVs</th>
<th>ELVs as % of total vehicles in use</th>
<th>ELVs as % of used vehicles registrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>188,713,997</td>
<td>14,767,042</td>
<td>173,946,955</td>
<td>12,368,509</td>
<td>6.6%</td>
<td>7.1%</td>
</tr>
<tr>
<td>1995</td>
<td>193,440,393</td>
<td>15,058,699</td>
<td>178,381,694</td>
<td>10,332,303</td>
<td>5.3%</td>
<td>5.8%</td>
</tr>
<tr>
<td>1996</td>
<td>198,293,459</td>
<td>15,663,707</td>
<td>182,629,752</td>
<td>10,810,641</td>
<td>5.5%</td>
<td>5.9%</td>
</tr>
<tr>
<td>1997</td>
<td>201,070,397</td>
<td>15,285,529</td>
<td>185,784,868</td>
<td>12,508,591</td>
<td>6.2%</td>
<td>6.7%</td>
</tr>
<tr>
<td>1998</td>
<td>205,042,639</td>
<td>15,637,540</td>
<td>189,405,099</td>
<td>11,665,298</td>
<td>5.7%</td>
<td>6.2%</td>
</tr>
<tr>
<td>1999</td>
<td>209,509,161</td>
<td>16,130,124</td>
<td>193,379,037</td>
<td>11,663,602</td>
<td>5.6%</td>
<td>6.0%</td>
</tr>
<tr>
<td>2000</td>
<td>213,299,313</td>
<td>18,088,911</td>
<td>195,210,402</td>
<td>14,298,759</td>
<td>6.7%</td>
<td>7.3%</td>
</tr>
<tr>
<td>2001</td>
<td>216,682,936</td>
<td>17,505,343</td>
<td>199,177,593</td>
<td>14,121,720</td>
<td>6.5%</td>
<td>7.1%</td>
</tr>
<tr>
<td>2002</td>
<td>221,027,121</td>
<td>17,639,934</td>
<td>203,387,187</td>
<td>13,295,749</td>
<td>6.0%</td>
<td>6.5%</td>
</tr>
<tr>
<td>2003</td>
<td>225,882,103</td>
<td>16,939,662</td>
<td>208,942,441</td>
<td>12,084,680</td>
<td>5.3%</td>
<td>5.8%</td>
</tr>
<tr>
<td>2004</td>
<td>231,398,281</td>
<td>17,419,471</td>
<td>213,978,810</td>
<td>11,903,293</td>
<td>5.1%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

recycling system, tracing the route of a retired vehicle through the steps of depollutioning (e.g., removing problematic fluids and materials so the car hulk can be further processed), selective dismantling, size-reduction through shredding, and final waste disposal.

2. ELV Management in the United States, European Union, Japan, and South Korea

2.1 United States

As mentioned before, about 10 to 14 million ELVs are generated every year in the United States. The management of ELVs involves dismantling, shredding, and recycling of parts and materials. The parts that have reasonable value are removed by the dismantlers, and then reconditioned and reused. The shredders group the remaining materials into ferrous and non-ferrous metals, which are all sent to recyclers. The material recycling rate in the United States is 75% by weight. The remaining 25% is composed mainly of automotive shredder residue (ASR) and fluff. Approximately 2.5 to 3.0 millions tons of ASR are produced and disposed of each year. Currently, 94% of cars in the United States are sent to dismantling and shredding facilities at the end of their service life (Das and Curlee, 1999; WMVD, 1996; Curlee, Randall T., 1994.)

There are no strict regulations regarding landfilling of ASR in the United States, as ASR is considered a non-hazardous waste. However, increasingly stringent regulations on waste landfills have increased ASR disposal costs. Only California has classified ASR as a hazardous waste, resulting in high management costs for ASR disposal.

Auto manufacturers have made developments towards using more plastic materials to reduce weight and increase fuel efficiency. This has resulted in increased ASR from shredders. The plastic content of automobiles has increased nearly 50% from 1976 to 1992. Due to the reduction in readily recoverable metals and increased ASR landfill costs, the economic benefits of automotive shredding could be eliminated.

To date, only one item of legislation has been proposed that specifically targets ELV management in the United States. This was the Automobile Recycling Study Act of 1991. The legislation would have required the US Environmental Protection Agency (EPA), in cooperation with the Department of Transportation and Department of Commerce, to perform a study on the potential for increased recycling of ELVs in the United States.

At a minimum, the study would have (Ecology Center et al, 2001):

- Identified major obstacles to increased recycling of auto components and developed new ways to overcome those obstacles.
- Defined methods for incorporating recyclability into the planning, design and manufacturing of new autos.
- Identified the toxic and non-recyclable material used in autos as well as possible substitutes for those materials.
- Studied the feasibility of establishing design standards for autos with the goal of gradually eliminating the use of hazardous and non-recyclable materials in autos.
- Examined methods for creating more recyclable plastics for use in autos

The bill also noted that automobile manufacturers must work in collaboration with raw material producers, materials suppliers, the automotive dismantling industry, the scrap processing industry, chemical process engineers and the recycling industry to develop a more recyclable automobile. This bill did not pass out of
the House Committee on Energy and Commerce.

Instead, the management of ELVs in the US has been effected by national legislation regarding solid and hazardous waste disposal practices, such as:

- Banning the disposal of free liquids in landfills, leading to the practice of collection of all vehicle fluids for subsequent recycling
- Banning the disposal of lead-acid batteries in landfills, leading to the practice of collection for subsequent recycling
- Applicable recycling regulations that govern management of vehicle fluids and batteries (Staudinger and Keoleian, 2001)

In order to reduce the environmental impacts of the entire life cycle of their vehicles, automotive manufacturers are attempting to improve the recyclability of their vehicles and thereby reduce the percentage of each car that must be disposed of in a landfill.

Specific ELV initiatives fall into four main categories:

- U.S. companies are preparing to comply with European regulations in their European manufacturing and sales operations.
- They are "importing" some of their recycling experience from Europe.
- They are attempting to prevent specific regulation in the U.S. by demonstrating voluntary progress in car recycling.
- They are anticipating and responding to competitive marketing pressures from European manufacturers that are expected to stress recycling as a positive attribute in the United States market in the future (Zoboli, Robert, et al., 2000)

One cooperative response from the United States industry was the creation of the Vehicle Recycling Partnership (VRP) in 1991 to promote and conduct research required for the technology to recover, reuse, and dispose of materials from retired cars. The VRP is currently part of the United States Council for Automotive Research (USCAR), formed by GM, Ford, and Chrysler in 1992 to strengthen the technology base of the domestic car industry through pre-competitive research.

The objectives of the VRP are:

- To understand issues involved with vehicle recycling, interact with other researchers, conduct research and development of technologies and methods to recycle materials and components from scrap cars and;
- To develop guidelines for design and material selection to facilitate recycling.

One major project of the VRP is the Vehicle Recycling Development Center, established in 1993 as the first Big Three joint research facility. The Center focuses on car dismantling and addresses a wide variety of concerns including fluid removal and recycling, economic analysis, polymers identification, seat and foam recycling, glass recycling, carpet and interior trim recycling, and instrument panel and bumper recycling. The VRP is working with the American Plastics Council on developing pyrolysis technology to decompose plastic wastes to a hydrocarbon gas and oil that can be used as a feedstock to produce new plastics.

2.2 European Union

The publication of Directive 2000/53/CE of the European Parliament and the Council of 18 September 2000 on ELVs imposed detailed targets for ELV management. It required reuse and recovery rates of 85% by 1 January 2006 and 95% by 1 January 2015; it also stipulated a reuse and recycling rate of 80% by 1
January 2006 and 85% by 1 January 2015. Among the basic points of the Directive are:

- Creation and building of systems for collection and recovery of end of life vehicles. The systems must be widespread, which means that they must be accessible to every vehicle owner.
- The availability of authorized process plants for disposal of used and scrap vehicles and the related issue of an evidence of the vehicle disposal.
- Free liquidation of the vehicle for the owner assuming that the significant components are not missing.
- Creation of a vehicle disposal process in order to reach valuation up to a high environmental standard.
- By 1 January 2015 at the latest, 95% of the vehicle weight must be reused or recovered.
- In order to reduce the production of dangerous automotive waste, the use of dangerous substances must be minimized during the vehicle design stage.

The Directive also established Extended Producer Responsibility (EPR) for ELV management. The EPR requires manufacturers and importers of automobiles to pay for the end-of-life costs associated with recycling. Beginning January 1, 2007, they are responsible for the recycling costs of all vehicles, regardless of age.

Other provisions of the Directive include Design for Environment (DfE) practices, increased quantity of recycled materials in automobiles, component and material coding for product identification and dismantling information for every vehicle. More stringent environmental standards include: registration of collection and treatment facilities, improvements in treatment facility design, and removal of fluids, hazardous materials and recyclable materials from ELVs before shredding. Finally, the Directive requires that all vehicles put on the market after July 1, 2003 contain no lead, mercury, cadmium, or hexavalent chromium, except in certain excluded components (e.g. lead in lead-acid batteries, hexavalent chromium as a corrosion preventative coating, lead-containing alloys of steel, aluminum and copper and mercury in headlamps).

2.3 Japan

The number of ELVs in Japan is estimated at 5 million units per year. The material recovery rate is about 75% and the amount of (landfilled) ASR is estimated at 800,000 tons per year. The ELV treatment operations are performed by an estimated number of 3,500-5,000 dismantlers. The dismantling sector is not considered to be well-organized and inappropriate treatment is assumed to result in adverse environmental impacts. There are a total of 140 shredding companies in Japan. The possibility of disposing of ASR by landfilling is decreasing as landfill capacity is expected to be depleted by 2008. Simultaneously, landfill costs are rapidly increasing and illegal dumping occurs (Funazaki A. et al., 2003; Kusaka K. 2002; JAMA, 2007).

Japan has no specific regulation on ELVs but various laws create a framework for ELV management. The Environmental Law of 1994 includes the objectives for waste reduction, reuse of end-of-life products, promotion of recovery, recycling and appropriate waste processing. The Waste Disposal Law, revised in 1997, introduced heavier sanctions on inappropriate waste management and created additional tasks for regional governments. Guidelines for waste processing and recycling became issues in 1997 following the Recycling Law of 1991 that considered the role of relevant social actors introducing waste recycling targets. The Recycling Law specifically addressed waste from car and other durables but with weak obligations.

In 1997, the Japanese car industry launched the ELVs Recycling Initiative which is based on voluntary action plans created by the industries in the ELVs chain (the Government, dealers, manufacturers, dismantlers, shredders). The objective of the Recycling Initiative is to promote car recycling without the
introduction of a new regulation specifically for ELVs. In order to reduce the ASR demand for landfill space and clean up the ELVs waste stream, it quantified targets for ELV recovery and encouraged innovation in car design. The organizational approach was based on the definition of tasks to be distributed among the various industrial actors as well as car users. The parties involved in the Recycling Initiative are: MITI (ministry of International Trade and Industry), JAMA (Japan Automobile Manufacturers Association), the Japan Auto Parts Industry Association, the Japan Automobile Dealers Association, the Japan Automobile Importers Association, the Japan Car Maintenance Promotion Federation, the Japan Subcompact Car Association, the Japan Used Car Dealers Association, the associations of dismantlers, and the Japan Steel Recycling Industry Association. The Recycling Initiative adopted the following specific targets:

- for the car industry: achievement of a recyclability rate of new vehicles at no less than 90% by 2002; reduction of lead content in new vehicles to less than 50% of 1996 level by 2000, and to less than 33% of 1996 level by 2005 (batteries excluded);
- for the other industrial partners: reuse/recovery rate of ELVs at no less than 85% by 2002 with ASR to landfill reduced at 3/5 of 1996 level by the same date; reuse/recovery at no less than 95% by 2015 with ASR to landfill reduced at 1/5 of 1996 level by the same date.

The action plans related to the Recycling Initiative consist of two levels: (a) the JAMA action plan; (b) the member company’s action plans.

The JAMA Action Plan mainly addresses the improvement of new car model recyclability and the reduction of their environmental impacts. The objectives are: (a) to define guidelines for the assessment of vehicles at the design stage; (b) to define guidelines for the calculation of recyclability of new models; (c) to reduce the lead content in new vehicles with priority given to specific parts; (d) to facilitate air-bag dismantling and disposal. The actions for vehicles currently in use and production included: (a) information dissemination about dismantling and materials contained in cars; (b) dissemination of information on appropriate disposal of ASR; (c) improved processing of parts and materials with the aim of dismantling/recycling; (d) increased use of recycled materials from ELVs and other products in car production; (e) increased use of recycled materials from ELVs in other applications. The plan includes cooperation with other industries working on ASR recovery and parts, as well as materials manufacturers involved in recycling operations. Cooperation with dismantlers for the treatment of ELVs and industries recovering air-bags and CFCs, is also pursued.

The development of plans by individual manufacturers started in 1998. They are based on the quantified targets described above and include: (a) technical developments on dismantling; (b) assistance to dismantlers; (c) preparation of dismantling manuals; (d) research on reuse of parts from ELVs; (e) technical research on energy recovery from ASR (Zobili R. et al., 2000).

2.4 South Korea

The management of vehicles at the end of their service life is conducted by vehicle recycling industries in South Korea. Except for parts restricted by law, reusable automobile parts are dismantled and then distributed by most recycling industries through the Internet for reuse. However, due to the small economic value of ELVs in Korea, the majority of ELVs and their parts are lost through overseas exporting. Tires and waste oil are managed by dismantlers, while useless parts, along with the ELVs, are collected by shredders. The shredders crush and shred the entire body of the ELVs and group the outputs into ferrous and non-ferrous metals. Currently, the recycling rate of ELVs is about 75% by weight. Every year, South Korea generates about 0.6 million end-of-life cars and trucks.
A policy for ELVs management in South Korea was first established in December 1982 as the Road Transportation Vehicle Directive, now known as the Vehicle Management Directive. Under this directive, the final owner of an ELV has the responsibility of delivering it to the auto dismantler. The owner also receives a certificate from the dismantler as proof of delivery and attaches it when canceling the car’s registration. Europe and Japan have similar ELVs management systems where ELVs certificates are needed for cancellation of registration.

In Chapter 2 Line 5 of the Vehicle Management Directive, an ELV is defined as “a car that the Department of Transportation classifies as not drivable and has to be crushed and separated along with parts that are not able to be reused or recycled.” In the Vehicle Management Directive, details of enforcement regulations concerning ELV parts and recycling industries are listed. The costs of reusing the salvaged vehicle parts should be reduced while the importance of reusing vehicle resources and materials is gradually increasing.

The Korean scrap vehicle industry was established in 1982 and, in order to broaden its operations and vehicle management capabilities, it was officially acknowledged as a commercial sector in 1995. In 1995, there were 141 scrap industries in South Korea, while in 2003, the number has increased to 310. Within a period of 8 years, the number of scrap industries has become 2.2 times larger. Furthermore, in 1993, each scrap industry dealt with 3,584 cars but decreased to 1,543 in 2002. However, the total number of scrapped cars increased 18.6% from 1995 to 2003, while in 2003, the number of scrapped cars per industry was 1,772 (Hong J. et al., 2004).

3. ELVs Recycling Process

3.1 Storage
Before being recycled, most cars and trucks are stored for some period of time in a salvage yard. Vehicles can be stored under cover or in open yards exposed to the elements. Storage yards can range in size from a few thousand square feet to 30 acres or more. The pollution potential of a storage yard depends on the following characteristics: substrate (i.e., surface vehicles are stored on: concrete, dirt, grass, etc.), vehicle exposure to elements; permeability of the soil; and storm water removal system. In addition, other activities (such as dismantling or fluid drainage) occurring in the storage yard can negatively impact the environment. (See Picture 1)

![Picture 1. Storage of ELVs in a salvage yard](image)

Currently most vehicles are dismantled as shown in Figure 1. Reusable and remanufacturable parts are
manually removed from ELVs by dismantlers. The other parts (so-called hulks) are sent to an automobile shredder, and the pieces are mechanically separated based on their material properties. By magnetic separation, ferrous scraps and nonferrous scraps are separated. The ferrous scraps are removed about 60~65%. The non-ferrous metals, such as Cu, Pb and Al, are separated into specific types of metal. The remainder of the car, about 25~30% by weight, is called Automotive Shredder Residue (ASR). The ASR, which consists of plastics, rubber, glass, dirt, fluids, and other materials, is currently sent to a landfill (Coulter S., Bras B., 1996).

3.2 Dismantling

Dismantling companies remove parts and depollute vehicles, i.e. they remove oils, fluids, batteries, etc. for subsequent recycling or disposal. These tend to be small family-run firms. Some larger dismantling companies have the facility to crush scrap vehicles prior to transfer to shredding facilities. The Picture 2 shows the dismantling process. The dismantling process consists of 3 parts as below.

- Fluid Drainage: In this step, all fluids are drained from the vehicle including oil, antifreeze, coolant, brake fluid, transmission fluid, and washer fluid. At larger sites of this type, distillation can be used to extract oil and grease, glycolates, acetates, and formic acids. Arsenic above regulatory limits remains in the sludge, necessitating hazardous waste treatment.

- Parts Removal: In this step, easily removable parts of the vehicle, both interior and exterior, are stripped. The purpose of this step is to remove as many parts as possible so that only the frame remains. This includes removing all seats, dashboard, carpeting, and windows. The parts are then, depending on their condition and market value, resold, recycled, or disposed in a landfill. Many of the removed parts are plastic which can now be recycled.
- Power Train Removal: This step consists of the removal of the engine, transmission, and axles. It is the final step before the vehicle is sent to the shredder.

3.3 Crushing and Shredding

Dismantlers that do not have shredding facilities, crush cars before they are transported to a metal recycler, who will shred the material. Crushers should be used on an impervious, fluid controlled surface, though this is not always true. Sites without such surfaces may contain contamination by fluids, or these fluids may have escaped to drain systems, or have been lost onto the ground. On older sites, non-metallic materials, known as “fluff” may have been buried on site. This may also be true of battery casings, tires, and other unmarketable materials. This situation might leave the site with PCB contamination from transformers.

The final step in automotive recycling is the shredder. The vehicle, drained of all fluids and stripped of as many parts as possible, is compacted and then sent through a shredder where the ferrous materials are separated from the non-ferrous materials then shredded. It is here that the real economic benefit of automobile recycling is realized. Shredding facilities are large, capital-intensive sites which process large tonnages of loose light steel. Picture 3 illustrates crushed ELVs and shredding process.
A grapple crane puts the hulks to the shredder. The shredder feedstock includes crushed ELVs but also other sources of scrap metals, such as waste home appliances. The main output from the shredding facility is shredded steel for use in the steel industry. Shredded steel comprises around 70% of the output from shredders, 25% is shredder fluff and the remainder, so-called, heavy media. Shredder fluff has high foam content, but essentially comprises a range of lightweight non-metallic materials. Shredder fluff is disposed of to landfill, although trials are underway to assess the feasibility of further separation of shredder fluff or the use of shredder fluff as an industrial fuel. The heavy fraction is a mixture of non-ferrous materials and dense non-ferrous substances such as rubber and concrete. This fraction is sent for further processing at heavy media plants where copper, aluminum, magnesium, glass and some plastics are removed. Traditionally, the majority of ELVs are recycled by the scrap industry, fuelled by the value
of the spare parts and scrap metal. However, scrap metal is an internationally traded commodity and fluctuating prices impact on ELVs (see Figure 2.).

Currently about 75% of an ELV can be recycled due to the recovery of ferrous component via a shredding process. ELVs consist of ~40% of a shredder in-feed and as such much of the non-ferrous fraction comes from these and sources of domestic white goods (also ~40% of in-feed). These waste products enter shredding facilities where they are size reduced within the shredder blades, to approximately tennis ball size, and a series of overband magnets and eddy current separators remove most (~90%) of the metallic component. After the dramatic size reduction, followed by the separation of the ferrous and non-ferrous metals from a scrap feedstock the residual material is called shredder residue or ‘light-fluff’. Currently this material is sent to landfill for disposal as no unique technology exists for ASR (Auto Shredder Residue) material separation.

Figure 2. Shredding operation process and materials separation
(Adapted from Bae, J. and Kim, J., 2006)
Reference


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