CIRCULAR ECONOMY AS PART OF THE MANAGEMENT OF END OF LIFE VEHICLES

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Abstract: An increase in the total number of motor vehicles in the world leads to a significant increase in the number of vehicles at the end of the life cycle.
Increasing the number of waste vehicles leads to the problem of dealing with hazardous waste that can cause great damage to the environment. End of life vehicles, hereinafter referred to as ELVs, waste management is becoming a major challenge for all countries of the world. End of life vehicles represent great potential for the application of a new type of economy, the so-called circular economy that sees waste as a potential resource that must be used in the most economical way. The circular economy represents a completely new approach to the treatment of resources and that can be very useful for the management of waste of the end of life vehicles. Recycling is a key element in the application of the circular economy in waste vehicle management. By recycling end of life vehicles we create a new value, achieve economic benefits by creating new jobs, and last but not least important by recycling of the End of life vehicles we directly affect on environmental protection by reducing the amount of waste that ends up in landfills. Serbia has legally regulated the procedure with ELVs, but in practice, unfortunately, that system does not function at the required level. The ELVs recycling system is not yet recognized as a huge potential for creating added value and protecting the environment. Recycling of ELVs must become an important segment of the future concept of the circular economy in Serbia.

Keywords: End of life vehicles, Waste management, Circular economy, Recycling.

1. INTRODUCTION

Motor vehicles in today's world are a widespread product of high technological complexity and have become inevitable in almost every corner of today's planet. Since the creation of the first motor vehicle intended for passenger transport, and it is believed that in 1886, when the German inventor Karl Benz made the Benz Patent-Motorwagen, motor vehicles have gone through many stages of technological innovation that led to the stage of development of today’s motor vehicles.

Today, as we mentioned, the motor vehicle is a product of high technological complexity, for the production of which dozens of different technologies are used, in which up to 15,000 different parts and assemblies are installed. The production of vehicles summarizes the ideas and technologies of mechanical engineering, electrical engineering, informatics, artificial intelligence, materials technology and other scientific fields, so the automotive industry is a complex conglomeration of multidisciplinary knowledge and technologies.

The automotive industry is the driving force of all developed economies in the world with tens of millions of employees and which significantly contributes to the economic and technological development of countries that have car factories and which have factories that produce parts and equipment for vehicle production

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The automotive industry is very important for all developed industries in the world and thus for the prosperity and economic development of the European Union, hereinafter referred to as the EU (6.8% of EU GDP), providing employment for 13.3 million people (6.1% of total EU employment), spreading innovation (about 54 billion investments, 8,700 patents) and delivering nearly 20 million new motor vehicles each year according to data provided by EAMA for the year 2018 [1].

The number of vehicles in use (passenger vehicles, buses, trucks) has already, according to data from 2010, exceeded one billion units (pieces). The EU and the United States, hereinafter referred to as the United States, account for half of the total number of vehicles, bearing in mind that there were 270 million vehicles in the EU by 2010, compared to 240 million in the United States that year. In countries such as China and India, due to intensive economic development, especially in China, there is a sharp increase in the number of vehicles. In China, the number of vehicles in 2012 had already reached 100 million. It is estimated that the number of vehicles globally in 2050 will reach 2.4 billion.

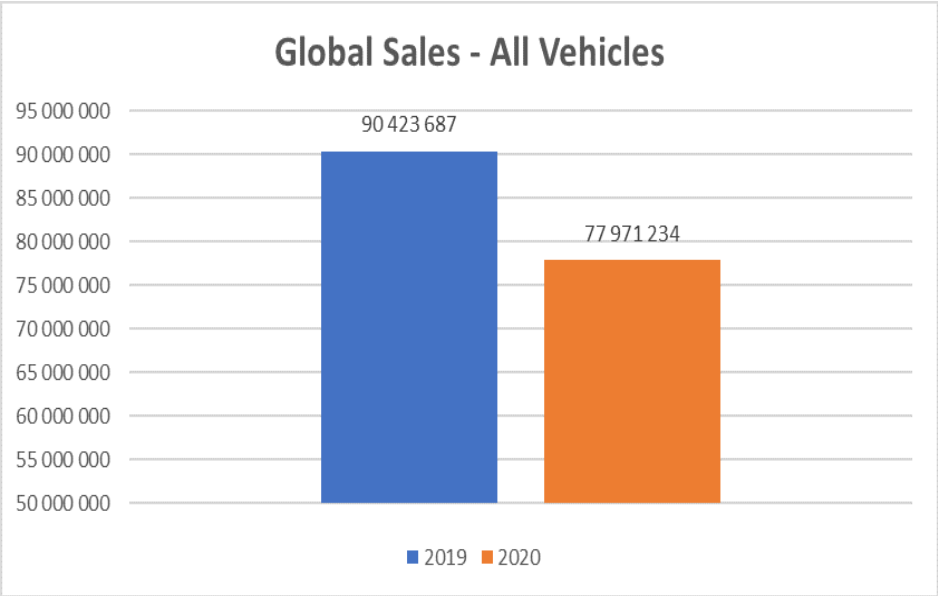

Figure 1. Global sales of all type of the vehicles

Such a large number of vehicles in use certainly means that every year a large number of vehicles will be at the end of their life cycle. According to the Association of Japanese Automobile Manufacturers [2], in 2010 alone there were 40.176.051 end of life vehicles in the world, which since then have been hazardous waste that can affect environmental pollution.

Designing a sustainable end-of-life vehicle management system is a very complex task for any society, given the damage they can have to the environment. Such a system must take into account energy recovery, recycling and reuse of ELV parts. All measures must be taken so that ELV does not end up in landfills or waste.

With this in mind, frequent approaches to solving this problem include issues of reverse logistics, material flow, cost-benefit analysis, sustainability analysis, modeling and simulations, as well as using circular economy to use waste as potential.

2. CIRCULAR ECONOMY

The classic linear economy, which means "take, make, spend and throw away" in the modern world has become obsolete while the so-called circular economy encourages producers

or business models of companies to have a closed circle in the supply of materials where waste is not a problem but waste becomes a resource.

Waste represents a large base for raw materials that can be used to reduce production costs, on the one hand, and on the other hand to make efforts to protect the environment.

Regarding waste motor vehicles, it is clear that waste (end of life vehicles) represents a huge source of potential raw materials, some of which are very scarce raw materials that are increasingly difficult to provide in nature, e.g. lithium and platinum.

Over time, the technology of motor vehicle production has changed so that the composition and types of waste have changed. It is clear that in the future the composition of the elements of waste vehicles will change significantly, bearing in mind the increasingly pronounced strategy of developed countries to switch to electric vehicles, hybrid vehicles and others.

3. MANAGEMENT OF THE END OF LIFE VEHICLES IN WORLD

Many countries in the world, especially the EU member states and Japan, adopted legal regulations on the treatment of vehicle waste more than twenty years ago.

3.1 MANAGEMENT OF ELVs IN EUROPEAN UNION

The basis for the start of end-of-life motor vehicle (ELV) treatment in the European Union was Directive 2000/53 / EC, which entered into force in 2000. The aim of the directive has been and still is to control the generation of waste from motor vehicles and to provide environmental awareness to all parties involved in the treatment of ELVs, through the promotion of reuse, recycling and collection of ELVs components.

The directive has completely changed the approach to this problem, the approach of all stakeholders in this process: financial investments, operational strategies, design, vehicle development process, etc. The process of development and design of motor vehicles takes place in accordance with the requirements of recycling. Moreover, the old ways of designing a vehicle will become more and more advanced as the regulation requires the removal of all harmful liquids and parts in the vehicle. All of this, of course, has posed major challenges for motor vehicle manufacturers to adapt to the new circumstances set out in this directive.

Other related legal requirements include Waste Electrical & Electronic Equipment (WEEE) Directive (2002/96/EC), Restriction of Hazard Substances (RoHS) Directive (2002/95/EC), the RRR-type approval Directive (2005/64/EC), issue of Certification of Destruction (CoD) for ELV handling (2002/151/EC), components and material coding standard for vehicles (2003/138/EC) and the detailed rules for monitoring compliance with the ELV Directive targets (2005/293/EC). The ensuing improvements in the identification of parts and materials, reduction in toxic substance use and design for disassembly in new cars have contributed to the increase in the levels of ELVs recycling and recovery.

In Europe, the total amount of material being recovered through the non-recycling route is also regulated, a minimum of 85% of the ELVs mass must be recycled and a maximum of 5% can be landfilled (95% recovery target).

3.2 MANAGEMENT OF ELVs IN JAPAN

In Japan, the Basic Environment Act was enacted in 1993 to define the fundamental principles and set the first policies on environmental protection. The Waste Management and Public Cleansing Act was later implemented to address the issues of illegal dumping, inappropriate storage and treatment of waste. The ELVs Recycling Act, which was enacted in 2002 and enforced from January 2005, was a turning point for the Japanese ELV recovery system.

While the ELVs Recycling Act has been guiding practices towards today's high level of recovery, the primary motivation for improving ELV recovery was the illegal disposal of whole ELVs (particularly on small islands), the illegal dumping of ASR and the lack of landfill space.

The recovery performance in Japan is measured based on the amount of material finally reaching landfill (e.g. 1% landfill = 99% recovery) as opposed to measuring the actual amount of material being reused, recycled and recovered.

4. MANAGEMENT OF THE END OF LIFE VEHICLES IN SERBIA

The Republic of Serbia has also recognized the problem of treating motor vehicles at the end of its life cycle, especially having in mind the strategy of joining the European Union. The Law on Waste Management was passed in 2009 when the legal regulation of waste management began, when the problem of waste management was recognized, its significant impact on the life of modern man, having in mind the protection of the environment, as well as its potential to be used as a significant resource.

In the Republic of Serbia, the largest percentage of motor vehicles is imported from abroad, of which the largest number are used vehicles. It is estimated that the average age of vehicles in the Republic of Serbia is over 17 years.

According to the data of the Republic Bureau of Statistics, over two million passenger vehicles are currently registered in the Republic of Serbia.

Table 1. Number of registered vehicles in Serbia [3]

Type of vehicles/year	2015	2016	2017	2018	2019
Mopeds	24845	24384	24837	24075	32504
Motorcycles	39396	40007	41596	38315	39515
Passenger cars	1834890	1888295	1968787	1999753	**2083753**
Buses	9482	9626	9929	9880	10441
Trucks	139886	140110	223629	228900	241241
Trailers	38551	38212	154310	154115	83971
Work vehicles	7052	8644	9439	8979	4586

Generating ELVs takes place successively, through the dynamics of fleet renewal and certainly by generating waste during the production and maintenance of cars. In any case, these are extremely large amounts of waste whose utilization should be maximized.

It is estimated that more than a million old motor vehicles, in various states of completeness, are waiting to be recycled, and that about 100,000 to 120,000 motor vehicles are out of service each year due to wear and tear, which gives an approximate weight of 1,000 kilograms per unit and 100.000.000 kilograms or 100,000 tons of potential waste.

4.1. RECYCLING OF END OF LIFE VEHICLES IN SERBIA

In 2010, the Government of the Republic of Serbia adopted the Waste Management Strategy for the period 2010-2019. year, where guidelines for the treatment of waste vehicles or vehicles at the end of the life cycle are also established.

As already mentioned, the potential of waste vehicles is very significant and should be used as much as possible. The choice of waste vehicle treatment technologies depends on many factors such as price, quantity, type, quality and location of the waste. The life cycle of a vehicle can be divided into the following phases:

1. Research and development;
2. Production;
3. Using;
4. Recycling of used motor vehicles;

Since Serbia cannot influence the life cycle of vehicles related to production, because the vast majority of vehicles on our roads are imported, largely used, with a smaller percentage of new vehicles, the focus of the Republic of Serbia should be on ELVs recycling.

The vast majority of new motor vehicles imported into the Republic of Serbia are vehicles whose manufacturers have long acted in accordance with the given directives, laws and regulations where the degree of vehicle recycling is prescribed, the percentage of recycled materials, as well as the ban on certain materials such as asbestos, hexavalent chromium, cadmium, etc.

Recycling includes the processing of used materials (waste) into new products to prevent the diversion of potentially useful materials, reduce raw material consumption, reduce energy consumption, reduce air pollution (due to incineration) and water pollution (due to waste disposal).

Recycling is the component of modern waste management and after prevention and revitalization (reduction) and reuse (reuse) it is the basic component of the hierarchy or the so-called waste management pyramids. Recycling is part of the well-known 3R system (Reduce, Reuse and Recycle).

Figure 2. Waste-Hierarchy-Pyramid

As can be seen in the picture, most needs to be done on prevention, restriction, reuse and then recycling, so that waste ending up in landfills is reduced to a minimum.

The waste management hierarchy shown in the Figure 2. replaces the traditional waste management approach of “the three Rs” (reduce, reuse and recycle), expanding it into a five-step process where the most preferred actions are at the top and the least preferred are at the bottom of the inverted pyramid.

The use of the waste management hierarchy came alongside the emergence of life cycle thinking in waste management policy, which looks at the totality of a product or service’s

environmental impact—from raw material extraction, processing and manufacturing to distribution, usage and disposal.

We have previously stated that in the Republic of Serbia, 100,000 tons of waste from motor vehicles are generated annually. This amount of waste represents an exceptional potential that must not be left untapped.

When we cite this potential data, we primarily mean that it is waste that has materials in its structure whose reuse significantly contributes to the elements of the circular economy, creating new value, new jobs, and at the same time reducing the impact of waste on environmental pollution.

Table 2. The average weight of some material per vehicle and the percentage of recyclability.

Material	**Weight per vehicle**		**Recyclability**	
	%	**kg**	**%**	**kg**
Ferrometals	68	680	90	612
Chassis	25	250	90	225
Other steel parts	28	280	90	252
Cast iron	15	150	90	135
Colored metals	6	60	90	54
Alloy of AlSi	4.4	44	90	39.6
Copper	1	10	80	9
Lead	0.6	6	90	5.4
Plastics and composites	8	80		
ABS	1	10	80	8
Polypropylene	1	10	80	8

The following table shows the average weight of certain materials found on waste vehicles with the percentage of their recyclability. As we can see, these are very important materials that can be used in various industries.

The percentage of recyclability of these materials is extremely high, which further emphasizes the need for their reuse.

Another important fact that further emphasizes the need for recycling is the energy required for the production of materials in the primary form or in the secondary form.

Energy consumption for the production of materials from secondary raw materials generated by the recycling process is significantly lower than that used to obtain materials from ores in primary production, as it is shown in the Table 2.

Table 1. Energy consumption for the production some of the materials

Material	**Energy required for primary production (kJ/kg)**	**Energy required for secondary production (kJ/kg)**
Steel	40000	18100
Iron	34000	24000
Aluminum	190000	26700

Copper	100000	45000

Previous table shows the incredible energy savings during production that can be achieved by using recycling used parts from the end of life vehicles.

It is estimated that 100,000 end of life vehicles is generated in Serbia annually. Taking estimated number of used cars in the consideration in the Republic of Serbia, as well as the percentage of utilization of materials per vehicle we obtain 68 000 tons of ferrous metals, 6,000 tons of nonferrous metals, 8,000 tons of plastics and composites, 1,400 tons of fluid, 5,000 tons of tires, 3,500 tons of glass, 1,000 tons textiles, 1,000 tons of batteries and 6100 tons of other waste from the used car.

This numbers show a very good potential for recycling and creation an economic benefits that is very important thing for the developing countries such as Serbia.

The recycling industry as a whole is very diverse and includes a wide range of services and productive economic activities, from those of processing and collection, to those that provide reuse of used parts or provide new products from recycled materials.

In addition to the economic benefits of the recycling system of used motor vehicles, no less important fact in the favor of the development of the recycling system, and its development in Serbia, is the contribution to environmental protection. Removal of environmentally harmful parts and substances; special oils, brake fluids, antifreeze, airbags, mercury, freon and the like - requires special treatment and expertise in the places of dismantling such waste.

End-of-life vehicle recycling is done chronologically, usually in six key phases:

- handing over the vehicle for recycling,
- removal of working fluids,
- disassembly of the vehicle into components,
- cutting,
- sorting, i
- processing.

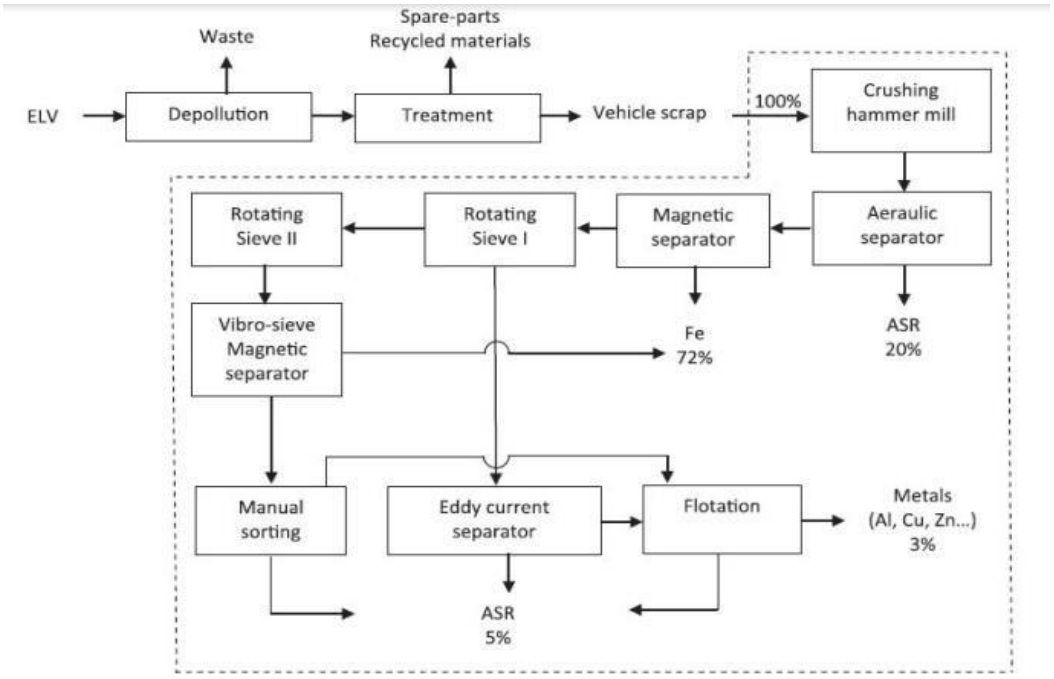

Figure 3. Scheme of treatment procedure of ELVs

The first three phases are crucial for the recycling process because in these phases materials are released that will be recycled in the further process.

Unfortunately, the process of recycling ELVs in Serbia is poorly developed or almost not developed at all. There are a large number of unconditional landfills in Serbia where there is no adequate technological treatment and the necessary expertise in the process in which hazardous substances are removed from the waste vehicle in a legally prescribed manner.

Figure 4. Illegal car dump

There are no recycling centers in which the dismantling of parts intended for recycling would take place, the government does not provide incentives for this activity, does not promote the importance of this activity in the right way.

The dismantling that takes place in the informal sector is crude and focuses on component reuse which are economically viable. However there is a need to prevent wastage of resources such as glass, brake oil, coolant, etc. These are simply discarded as they fetch marginal or no value, and there are hardly any storage systems available currently.

There is also no depollution procedure being followed in most of these informal scrap yards, and the hazardous fluids from the ELVs are spilled and disposed of on the ground where the ELVs are handled. In such units, the whole area is often contaminated with oil, coolants, and other fluids. Toxic gases such as AC gas are released into the air generating several environmental hazards and occupational safety hazards.

Unfortunately, we can still see such illegal car waste in many places in Serbia, where waste vehicles are placed directly on the ground, which leads to contamination of land and groundwater, where illegal dismantling of those parts and systems on the vehicle whose reuse is strictly prohibited (parts of the braking system, parts of the steering system, etc.)

4.2 SHREDDING OF ELVs

At the end of its journey through the disassembly process, the car can be pressed. It is thus more suitable for transport to the next step: shredding (shredding). the "schroeder" machine, a pressed waste vehicle, passes through the "hammer mill", it cuts the car into pieces the size of a fist. The ferrometals are then separated by a magnetic process while the separation of non-ferrometal residues takes place by air separation. heavier parts after air separation are then sent to a non-ferrometal separator in which the vortex separator isolates non-ferrometal materials.

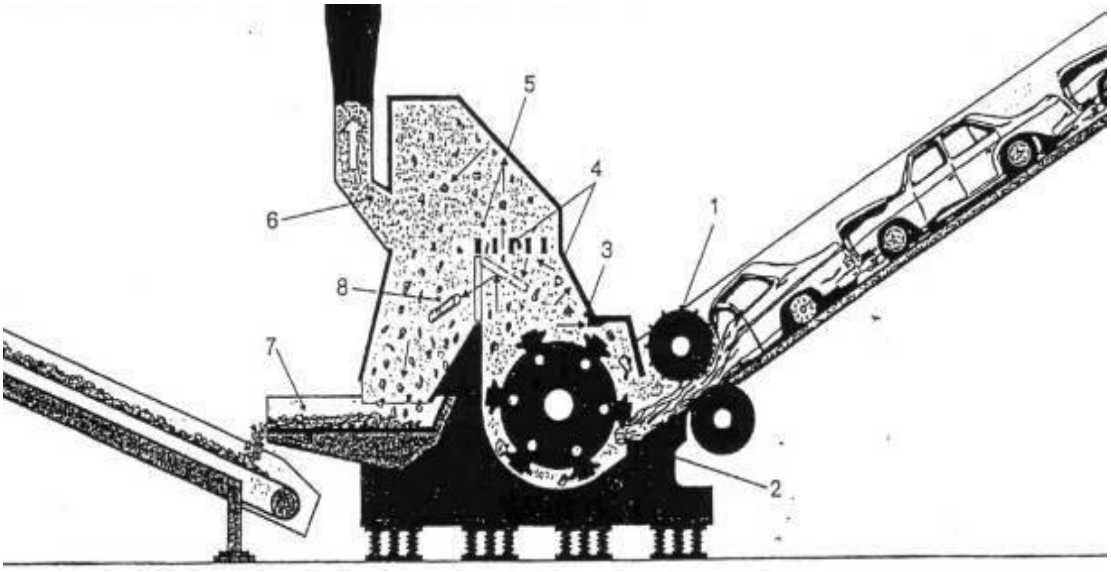

Figure 4. „Lindemann 1/1250 STVCar Shredding System& Non-Ferrous System“.

The remaining part of the car is called the rest after chopping-crushing the car (Auto Shredder Residue). It accounts for about 20 to 25% of the total weight of a used vehicle and it represents a weak point in the vehicle recycling process. This residue, despite being toxic enough to be considered hazardous waste, can also be considered an energy source as it contains more than 7% fuel.

Many alternatives have been developed for the processing of this type of residue (physical separation, incineration, pyrolysis), but it seems that landfilling is currently the most acceptable solution, primarily due to the high cost of their processing. However, some countries, such as Japan, which is spatially limited and densely populated, where the cost of landfilling is extremely high, are taking steps to remove the residue after crushing and shredding (ASR).

The residue after crushing the vehicle (ASR) is used in the economy, metal residues are returned to the production of materials, a certain part can be burned in controlled conditions and converted into another type of energy (water heating, electricity generation, etc.) and thus returned part of the invested energy. Some of the materials are also used in the construction industry, for example. in the road construction industry, as part of the material that is installed in roads, etc.

5. CONCLUSION

The current linear economy approach results does not allow us to close the loop from production to consumption to secondary resource management and channeling back of these resources back into the economy.

One of the major issues that the world is currently grappling with is the unprecedented growth in demand for various resources and the associated challenge in meeting this demand.

The outcome has largely been driven by the rapid industrialization of emerging economies, as well as the continued high levels of material consumption in developed countries, although some evidence of absolute decoupling in certain developed regions of the world have been observed in recent times, led by the European Union (EU).

Never in the past has the conflict between economic growth and resource consumption found such high attention by different stakeholders as has been observed in the recent times.

Developing countries too are experiencing the pressure on demand for resources and this is only likely to increase in the future due to many factors including growing population, rising aspirations of the vast middle class, demand for improved lifestyles and increased urbanization.

It will be necessary in the future to ensure high-grade recycling capacity with the aim of recovering lithium, cobalt, and other metals used in traction batteries which is important from an ecological and industry-specific point of view.

From all the above, it can be concluded that the management of waste vehicles (ELVs) represents a significant potential in the light of the application of the concept of circular economy and which will certainly gain more and more importance in the future.

Serbia also needs to recognize these trends and prepare conditions and incentives for the development of the end of life vehicles recycling industry. Such an approach will be useful in many ways, both in economic terms and in terms of environmental protection.

It is certain that in the future, the concept of circular economy will become more and more important. Waste vehicle management largely relies on the concept of circular economy, trying to return as much of the material on vehicles as possible to reuse in vehicle production or in the production of some other materials.

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