Module 10

End of Life Vehicle Disposal

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Recycling processes – WEEE disassembly and recycling industry

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1 OVERVIEW

The paper "*Recycling Processes - WEEE Disassembly and Recycling Industry*", presents the concepts, foundations, principles, solutions of modernized technologies and services integrated in the intelligent manufacturing of products regarding the recycling processes of the WEEE dismantling and recycling industry.

Intelligent manufacturing involves the transformation of technical and technological part of intelligent design within enterprises/industries, either total or partial for the entire architectural and functional ensemble regarding the improvement of recycling processes in the WEEE disassembly and recycling industry.

The transformation of intelligent manufacturing also assumes that all vehicles that will be made will undergo new design processes using new materials that can be easily recycled, thus offering modernized services, integrated in the intelligent manufacturing of electrical and electronic products.

Thus, this smart manufacturing transformation creates unprecedented challenges in the design, connectivity, capacity, safety and security of smart manufacturing processes to bring the next generation of automobiles to market.

The value chain is a model developed by Michel Porter (American academic known for his theories on economics, business strategy, and social cause) being a strategic management tool in the intelligent manufacturing process, which details how the value of a company in the industry is created or globally. Moreover, the intelligent application of this model can lead to the identification of opportunities necessary to reformulate strategies and operations within an enterprise or industry globally. In this value chain model, there are two types of activities in which businesses/industries are involved: main/support activities, or secondary activities. Regarding the main activities of this value chain, they are to transform raw materials into products and services that ensure the delivery of the benefits expected by customers. [1]

The transformation of the activities in the value chain of the companies in the automotive industry offers enormous potential for innovation and the creation of added value, for increasing productivity by optimizing the recycling processes of the waste obtained from the electrical and electronic equipment of cars.

Thus, this paper presents the new generation of advanced mechatronic engineering, which creates and incorporates new advanced engineering sciences, which for the future will develop new recycling processes in the WEEE disassembly and recycling industry.

This work aims to promote the identification of new methods, process, technologies and ecological solutions, for the disassembly and recycling of WEEE from the automotive industry starting from the collection, sorting, transport, treatment, disposal, recovery and recycling of this waste. Thus, the work covers all types of waste in an integrative manner from all waste sources, especially WEEE/E-waste from the automotive industry.

The further development of intelligent mechatronic, integronic and adaptronic systems favors the development of the intelligent automobile industry, in this case the development of the intelligent automobile, which will be increasingly based on the design and production of electrical and electronic equipment that can ensure the three ***R: Recovery, Reusing and Recycling*** them.

1.1 Objectives

The present paper is a help to both students from the faculties of mechanical profile and students from the faculties of environment, in developing the awareness capacity regarding the protection of the environment to understand the need to reduce waste, to plan the design and production of electrical and electronic equipment that can ensure their 90% recovery and recycling, as well as broaden the vision of the possibility of implementing modern WEEE/E-waste "reduction" schemes that can be applied to the automotive industry in a city/geographical area or country.

1.2 Description

This manual includes the regulated system regarding Waste Electrical and Electronic Equipment (WEEE) from the disposal of end-of-life vehicles (ELV's), their collection, sorting and transport system, as well as the highlighting of concrete case studies from Romania, including the description of the various electrical components and automotive electronics.

The preparation of this handbook involved the collection of data from secondary sources, including publications in scientific journals, reports and websites. Thus, a case study approach was adopted to provide examples of recycling solutions and processes so that analytical thinking can be adopted from the design phase of new electrical and electronic equipment serving the automotive industry.

The manual can be used in all countries where projects have been initiated on the disposal of Waste Electrical and Electronic Equipment from the disposal of end-of-life vehicles.

1.3 Definitions

In our country, the measures to prevent the production of waste from ELV's and the collection, reuse, recycling, as well as other forms of valorization of them and their behavior, in order to reduce the amount of waste intended for disposal, are regulated by GD no. 2406/21.12.2004 regarding the management of end-of-life vehicles. [2]

The following definitions will be used in the work according to GEO no. 78/2000, approved with amendments and additions by Law no. 26/2001:

- *Vehicle* – any vehicle belonging to categories M or N, as well as 3-wheeled vehicles, as defined by Order of the Minister of Public Works, Transport and Housing no. 211/2003, with the exception of motorcycles;
- *End-of-life vehicle* (ELV's) – a vehicle that has become waste;
- *Manufacturer* – the vehicle manufacturer or the professional importer of a vehicle in Romania;

- *Individual manufacturer* – natural or legal person who produces or imports vehicles, but who does not carry out this activity professionally;
- *Prevention* - the measures aimed at reducing the quantity and harmfulness to the environment of end-of-life vehicles, materials and substances in their composition;
- *Treatment* - any activity carried out for depollution, dismantling, cutting, shredding, recovery or preparation for the disposal of shredded waste, as well as any other operation carried out regarding the recovery and/or elimination of end-of-life vehicles and behaviors;
- *Re-use* – any operation by which the components of vehicles taken out of use are used for the same purpose for which they were designed;
- *Recycling* – the reprocessing of waste in a production process in order to use it for the original purpose or for other purposes, but excluding energy recovery;
- *Energy recovery* – the use of combustible waste as a means of generating energy, through direct incineration or co-incineration, with or without other waste, but with heat recovery;
- *Removal* - any of the operations provided for in annex no. IIA to Government Emergency Ordinance no. 78/2000, approved with amendments and additions by Law no. 426/2001;
- *Economic operators* - manufacturers, distributors, collectors, insurance companies, as well as agencies whose business is the treatment, recovery, recycling of end-of-life vehicles, including their components and materials;
- *Dangerous substance* - any substance considered dangerous according to art. 7 of the Government's Emergency Ordinance no. 200/2000 regarding the classification, labeling and packaging of dangerous chemical substances and preparations, approved with amendments by Law no. 451/2001;
- *End-of-life vehicle shredding* facility (shredder) – any facility used for cutting into pieces or for fragmenting end-of-life vehicles, including for the purpose of obtaining directly reusable metal scraps;
- *Dismantling information* – all the information necessary for the proper and environmentally sound treatment of end-of-life vehicles. This information will be made available to economic agents that own treatment facilities authorized by vehicle manufacturers and component manufacturers in the form of manuals or on electronic media, such as CD-ROM, online services;
- *Replacement part* – part intended to replace in a vehicle that part with which the vehicle was type-approved;
- *Depollution* – the emptying of fluids and dangerous chemical substances from vehicles taken out of use, in compliance with the legal provisions;
- *Certificate of destruction* – the certificate issued to the last owner of the vehicle taken out of use by the authorized units for collection/treatment.

By that decision, measures are established for the improvement from the point of view of environmental protection, of the activities of economic agents involved in the life cycle of vehicles and, in particular, of economic agents directly involved in the treatment of end-of-life vehicles. This applies in compliance with national legislation regarding safety standards, emissions into the atmosphere and the level of noise emissions, as well as those related to soil and water protection.

The provisions of this decision apply to end-of-life vehicles (ELV's), including their components and materials, regardless of how the vehicle has been maintained or repaired throughout its use and regardless of whether it is equipped with the components provided by the manufacturer or with other components whose mounting as spare parts or as replacement parts is carried out in compliance with the national regulations in the field.

1.4 Legislation

The normative acts that form the basis of the management of waste from electrical and electronic equipment are the following:

- ***European WEEE management legislation***
  - Directive 2002/95/EC on restrictions on the use of certain hazardous substances in electrical and electronic equipment
  - Directive 2012/19/EC on WEEE management.
  - Regulation 699/2017 establishing a common methodology for calculating the weight of electrical and electronic equipment (EEE) introduced on the market of each member state and a common methodology for calculating the amount of waste electrical and electronic equipment (WEEE) generated
  - WEEE legislative news at European level
- ***National WEEE management legislation***
  - GEO 5/2015 regarding electrical and electronic equipment waste
  - OM 1494/2016 regarding the approval of the procedure and criteria for evaluation and authorization of collective organizations in order to take responsibility for the achievement of the annual objectives of collection, reuse, recycling and recovery of waste from electrical and electronic equipment, with the amendments and subsequent additions
  - OM 1441/2011 regarding the establishment of the methodology for establishing and managing the financial guarantee for manufacturers of electrical and electronic equipment;
  - OM 269/2019 regarding the approval of the Procedure for establishing the registration, reporting, reporting frequency to the National Register of Producers, as well as the way of recording and reporting the information provided for in art. 9

para. (4) and in art. 27 para. (6) from Government Emergency Ordinance no. 5/2015 regarding electrical and electronic equipment waste

- OM 556/2006 regarding the specific marking applied to electrical and electronic equipment introduced on the market after December 31, 2006
- OM 739/2017 regarding the approval of the Registration Procedure of economic operators that are not subject to environmental authorization according to the provisions of Law no. 211/2011 regarding the waste regime

➢ ***National RoHS legislation***

- HG 322/2013 regarding restrictions on the use of certain hazardous substances in electrical and electronic equipment
- OM 1601/2013 for the approval of the list of applications benefiting from the exemption from the restriction provided for in art. 4 para. (1) from Government Decision no. 322/2013 regarding restrictions on the use of certain hazardous substances in electrical and electronic equipment

➢ ***Other relevant national acts***

- Law 132/2010 regarding the selective collection of waste in public institutions
- HG 856/2002 regarding the record of waste management and for the approval of the list including waste, including hazardous waste
- GEO 195/2005 on environmental protection
- HG 1061/2008 regarding the transport of hazardous and non-hazardous waste on the territory of Romania
- OM 1422/2016 for the approval of the Registration Procedure at the Ministry of Economy, Trade and Relations with the Business Environment of economic operators that carry out waste recovery operations

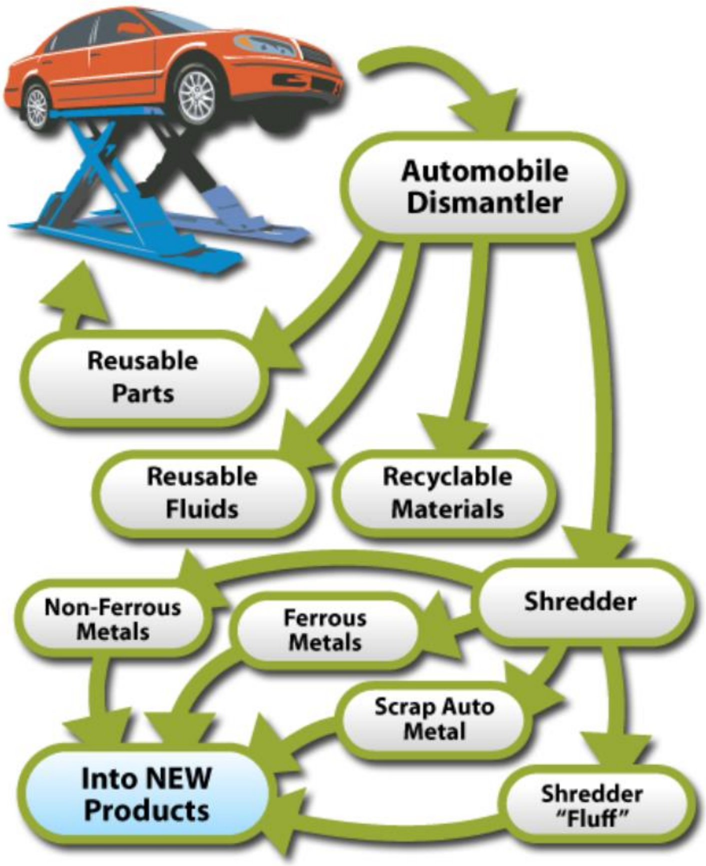
2 WEEE POLICIES

The rapid increase in the consumption of electrical and electronic equipment (EEE) that characterizes the last decades, becoming indispensable in today's modern society, produces a consequence proportional to the increase in electronic waste.

The rapid development of research in the field of mechatronics, electronics, information technology and digital communications, generates the modernization of products creating an intelligent planet, causes the population to buy new types of more efficient products in order to reduce energy consumption.

The collection of waste from electrical and electronic equipment is influenced by several factors, such as the decision of consumers to collect the products according to the regulations in force, the development and adoption of viable strategies for the collection and management of WEEE.

In these conditions, the recycling of electrical and electronic equipment from automotive industry becomes vital, especially since this process has an economic and environmental motivation due to the materials that could be recovered. Unfortunately, there are huge differences between the various types of electrical and electronic equipment and their composition can vary from one product to another. Moreover, the economic value of recycled products depends a lot on the value of the recovered materials as well as on the equipment used in the use of recycling technologies.



2-1. Figure_ WEEE Management [https://www.wreckit.com.au/how-to-dismantle-a-car/]

2.1 Directives and regulations

An active and main role in protecting the environment belongs to any legal/natural person, using an EEE. Therefore, each of us has the obligation to actively contribute to the 3Rs as well as the Re-use in other forms of use of EEE.

Used devices, towards the end of their working life, become waste electrical and electronic equipment (WEEE). Thus, randomly thrown or improperly treated WEEE are dangerous because they contain toxic substances (mercury, lead, chromium or cadmium). These being very harmful both for the environment and for people, to whom they can cause serious health conditions.

In order to revalue resources and educate users in order to protect the environment, the Romanian legislation on the correct management of WEEE (Emergency Ordinance 5/2015 on waste electrical and electronic equipment) provides for sanctions for any natural or legal person who throws away WEEE instead of handing it over to specially arranged collection centers.

According to emergency romanian ordinance no. 5/2015 on electrical and electronic equipment waste (EOG 5/2015), the producer is any natural or legal person who, regardless of the sales technique used, including remote communication […]:

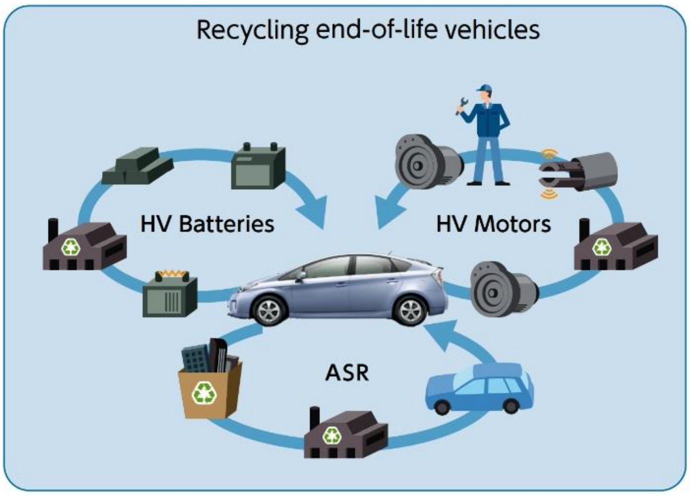
(i) is based in Romania and manufactures EEE under its own name or trademark or whose EEE is designed or manufactured and marketed under its own name or trademark, on the territory of Romania; - those who actually have a factory in Romania where EEE is produced.

(ii) is based in Romania and resells on Romanian territory under its own name or trademark equipment produced by other suppliers, a reseller not being considered a "producer" when the manufacturer's brand appears on the equipment according to point (i); – those who purchase EEE, personalize them with their own EEE brand and put them up for sale again.

(iii) is based in Romania and introduces on the national market, with a professional title, EEE from a third country or from another member state of the European Union; – those who import EEE.

(iv) sells EEE by means of remote communication directly to private households or users outside private households, in Romania and is based in another member state or in a third country – exporters of EEE from outside Romania who sell online in Romania.

Both manufacturers and sellers of electrical and electronic devices in the EU are responsible for the collection and recycling of end-of-life products, i.e. WEEE, from 2021 onwards. This entails registration, reporting, information and labeling obligations, according to the legal basis (EU WEEE Directive 2012/19/EU), which changes the original 2004 directive.



2-2. Figure_ End of life vehicles disposal [https://global.toyota/en/download/3785586/]

Over the years, many non-EU countries have adopted similar laws for the collection and recycling of end-of-life electrical and electronic devices, thus making similar obligations as in the EU valid on a more or less global scale.

The obligations of WEEE producers, in accordance with EU laws regarding their manufacture and recycling, are:

- Evaluation of individual obligations as a producer or seller of EEE;
- Creation of a customized compliance roadmap;
- Registration of all necessary documents with the national authorities;
- Adherence to the national compliance schemes of manufacturers;
- Preparation and transmission of sales data to national authorities and/or collective compliance schemes;
- Auditing invoices related to WEEE;
- Adapting or optimizing the compliance configuration;
- Adapting and complying with changes to EU legislation.

The registration in the National Register of EEE Producers in Romania for the year 2022 is:

RO – EEE – 0701 – 2022 – 05 – 25

During the 2022 year, a number of obligations were introduced to the environmental authorities regarding importers of products and EEE. The main one would be the obligation of WEEE producers to register in the National Register of EEE producers, within the National Agency for Environmental Protection (ANPM), before their introduction on the market.

In Romania, at the moment, the National Waste Management Strategy (SNGD), revised in 2013 and approved by GD 870/2013, establishes Romania's policy and strategic objectives in the field of waste management for the period 2018-2025.

Both the National Waste Management Plan and the National Waste Prevention Program (PNPGD)[3] are developed in accordance with the legal provisions in force, as well as with the existing European guidelines ([WMP Guide 2012], [WPP Guide 2012]).

According to the legal provisions in force, PNGD and PPNPGD are evaluated at least once every 6 years and revised, as appropriate, by the central public authority for environmental protection, based on the monitoring report drawn up by the National Agency for Environmental Protection. PNGD and PNPGD are monitored annually by the National Agency for Environmental Protection.

The regulations in the field of EEE establish the limit values for the use of chemical substances such as ***lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers*** in certain types of electrical and electronic equipment. These regulations have prevented the disposal or potential release into the environment of thousands of tonnes of banned substances and have led to important changes in product design in the European Union and around the world, while also serving as a model for similar laws adopted by countries outside European Economic Area.

The new legislation will help increase the safety of electronic products such as ***thermostats, medical equipment and control panels***, while also preventing the release of hazardous substances into the environment.

Through the new legislation, the responsibility for both WEEE management and the provision of data on the quantities of EEE introduced on the market rests with producers/importers.

The regulations in the field of waste electrical and electronic equipment (WEEE) management have the following as their main objectives: **prevention of the occurrence of WEEE and the reuse, recycling and other forms of valorization of these types of waste in order to reduce to the greatest extent the amount of disposed waste**; improving the environmental performance of all operators involved in the life cycle of electrical and electronic equipment (producers, distributors and consumers) and in particular economic operators directly involved in the treatment of electrical and electronic equipment waste.

The wastes that are the subject of planning are those regulated by Law no. 211/2011 on the waste regime, with subsequent amendments and additions, which transposed Directive 2008/98/EC of the European Parliament and of the Council of November 19, 2008 on waste and repealing certain directives. Therefore, industrial waste is part of PNGD.

The 7th Environmental Action Program sets the **priority objectives** regarding EU policy in the waste management sector, respectively:

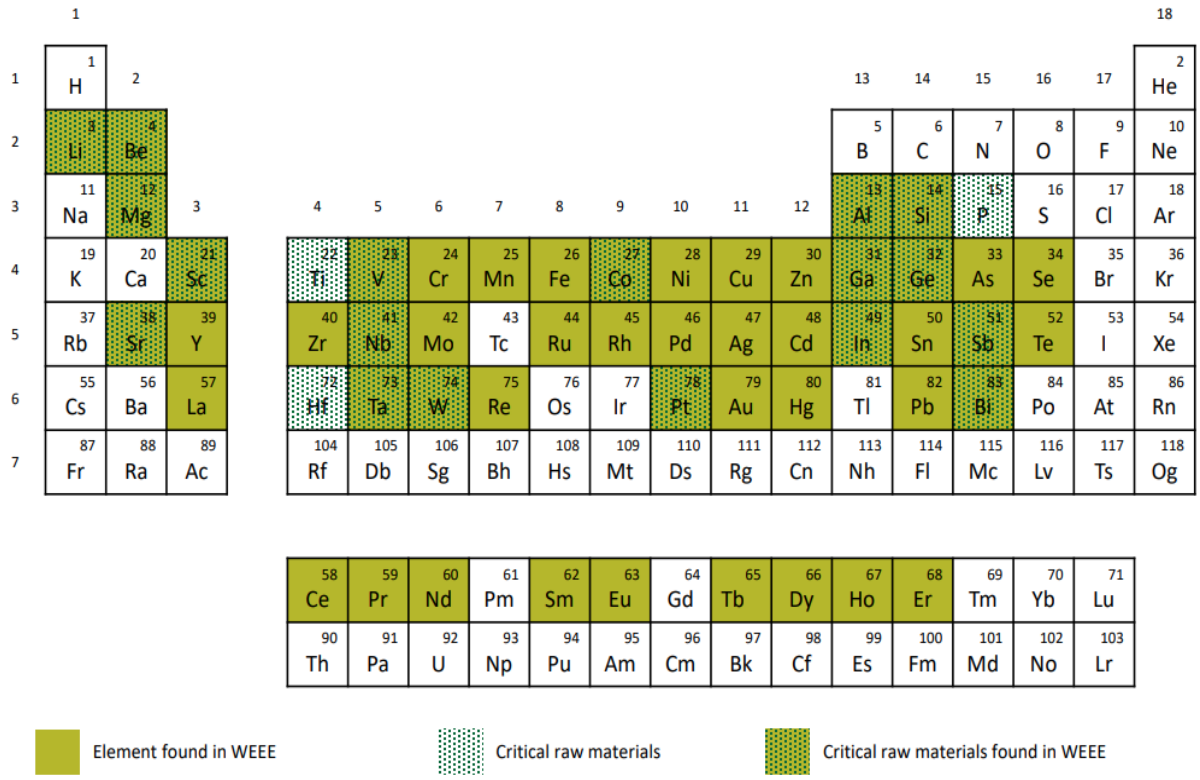
- **Reducing** the amount of waste generated
- Maximizing **reuse and recycling**
- **Limiting incineration** to non-recyclable materials

- Progressive **limitation of storage** to waste that cannot be recycled or recovered
- **Ensuring full implementation of waste policy objectives** in all member states.

The treatment of WEEE must be carried out properly, because if they are not treated properly, they are harmful to the environment, due to their content of complex combinations of highly toxic substances. Burning untreated WEEE can release dangerous chemicals such as dioxins. [4] The use of certain metals in such equipment, such as lead and mercury, has been restricted in the EU since 2003 [5], but these are still present in older products.

Significant economic benefits can be brought to companies by the proper treatment of e-waste, which can reduce the demand for raw materials. For example, 1 ton of smartphones contains about 100 times more gold than 1 ton of gold. [6] E-waste may also contain other important metals such as copper, nickel, indium or palladium. [7] It is known that e-waste recycling also contributes to mitigating climate change, given that it avoids greenhouse gas emissions resulting from the production of new materials, especially metals. [8]

The EU-funded ProSUM-7 project identified 49 chemical elements present in WEEE, many with the potential to be recycled for use in other products. [9] The European Commission has listed 18 of these 49 elements as critical raw materials, i.e. economically important materials with a high supply risk. [10]



2-3. Figure_ Chemical elements found in WEEE and critical raw materials, highlighted in the periodic table of elements
[ECA, based on data from the Urban Mine Platform and the European Commission]

The EU has published e-waste legislation for the first time in 2003 (the first WEEE Directive [11]). This directive encouraged collection systems that allowed consumers to return their WEEE free of charge, based on the principle of "extended producer responsibility". In 2012, the EU adopted a "reform" directive (the second WEEE directive). [12]

According to the WEEE Directive, Member States must ensure that systems are in place for the free return of e-waste (to the final holder). [13] Manufacturers of electrical and electronic equipment finance the respective schemes in proportion to their market share by type of equipment, based on arrangements that vary from one Member State to another, established in accordance with the minimum requirements set out in the Waste Framework Directive [14] and the WEEE Directive.

The approach of other directives regarding ***"Producer Responsibility"*** obliges economic operators to organize the treatment, reuse, recycling, valorization or disposal of waste derived from their products, covering the costs related to these actions.

The directives that promote this principle are:

- Electrical and electronic equipment - EEE (Directive 2002/96/CE) - transposed by Government Decision no. 1037/2010 regarding electrical and electronic equipment waste.
- Portable batteries and accumulators (Directive 2006/66/EC) – transposed by Government Decision no. 1132 / 2008 regarding the regime of batteries and accumulators and battery and accumulator waste.

Waste management is a broad term used to denote the collection, transport, recovery and disposal of all types of waste. [15] The WEEE Directive contains provisions on the following e-waste management operations: separate collection of WEEE, appropriate treatment, shipments of WEEE, recovery (including recycling and preparation for re-use) and ecological disposal.

The CLEPA statement – European Association of Automotive Suppliers – Brussels, 04/07/2018, on the applicability of ELV vs RoHS / WEEE in the automotive industry, helps companies to define which directives apply to the parts to be recycled, either the ELV directive or the RoHS/WEEE directive. These statement proposes that electric vehicles represent 53÷82% of all new vehicles under 3.5 tonnes that will be sold in Europe by 2030. These uses the following directives as a legal basis:

- Directive on end-of-life vehicles 2000/53/EC (ELV's)
- The ELV's applies to vehicles, including vehicle components and materials, as defined in Article 3(1).
- ELV's focuses on the recycling of vehicles, introduced on the European market. In addition, it restricts the use of certain substances in vehicles.

Waste Electrical and Electronic Equipment **Directive 2012/19/EU (WEEE)**

- As of 15 August 2018, WEEE applies to electrical/electronic equipment (EEE) as defined in Article 2(1). It also excludes specific EEE for means of transport (Article 2(4)). This exclusion applies to vehicles that fall within the scope of the ELV.
- WEEE focuses on the recycling of EEE introduced on the European market.

Restriction of the use of certain hazardous substances in electrical and electronic equipment **Directive 2011/65/EU (RoHS)**

- RoHS applies to EEE as defined in Article 2(1). It also excludes specific EEE for means of transport [Article 2 letter (f)]. This excludes vehicles that fall within the scope of the ELV.
- RoHS focuses on restricting the use of specific substances in EEE, introduced on the European market.

Another serious problem is the construction of a disassembly system, which is quite difficult to achieve. Applicability for vehicle parts containing EEE (non-exhaustive examples):

- Systems or parts, which are specially designed for the vehicle and which are essential for the safe operation of a vehicle → The ELV Directive applies to:
- Electric wipers;
- Vehicle electric keys;
- Car lighting systems;
- Tire pressure monitoring systems.

Installed assistance or entertainment systems or parts that are specially designed for the vehicle:

- Multimedia systems for vehicles;
- Installed navigation systems;
- Electric window systems;

Mobile support systems or parts, which could also fulfill a non-automotive function:

- Mobile navigation systems;
- Warning triangles with flashing function;
- Chargers for mobile phones.

According to the Munich/Brussels meeting, 8 September 2022 – it is specified that the ongoing electrification transition in the automotive sector indicates a massive change for the aftermarket in Europe. The reasons being that battery electric vehicles (BEVs) have about 30% lower demand for traditional aftermarket components, and BEV sales forecasts predict a market share of 53 to 82% in 2030. These are the findings of a joint study by Roland Berger and CLEPA. Also, according to ***the European Commission,*** every year ELV's generates between 8 and 9 million tonnes of waste in the EU. Thus, Directive 2000/53/EC on end-of-life vehicles, establishes measures to prevent and limit waste from end-of-life vehicles (ELV's) and their components, ensuring their reuse, recycling and recovery. It also aims to improve the environmental performance of all economic operators involved in the life cycle of vehicles. (according to PNGD)

The key aspects subject to the debate of Directive 2000/53/EC are:

- Vehicle and equipment manufacturers must consider vehicle disassembly, reuse and recovery during product design and construction. They must ensure that new vehicles are:
    - reusable and/or recyclable in proportion to at least 85% of the vehicle's weight;
    - reusable and/or recoverable to a minimum of 95% of the weight per vehicle.
- They are not allowed to use hazardous substances such as lead, mercury, cadmium and hexavalent chromium.
- Manufacturers, importers and distributors must provide systems for the collection of ELV's and, as far as technically possible, used parts removed when repairing passenger cars.
- Owners of ELV's handed over for waste treatment receive a certificate of destruction. This is required for vehicle registration.
- Manufacturers must cover all or most of the costs involved in delivering a ELV's to a waste treatment centre. As for the vehicle owner, they should not incur any expenses when delivering a ELV's to an authorized waste treatment center, except in rare cases where the engine is missing or the ELV's is full of waste.
- Waste treatment centers must apply for a permit or register with the competent authorities of the EU country in which they are located.
- ELV's are dismantled before further treatment. Hazardous substances and components are removed and separated. Attention is paid to the potential for reuse, recovery or recycling of waste.
- There are clear quantified targets for annual reporting to the European Commission on the reuse, recycling and recovery of ELV's and their respective components. They have become more and more demanding.
- The legislation applies to passenger vehicles and small trucks, but not to large trucks, vintage vehicles, special purpose vehicles and motorcycles.

But ***Directive (EU) 2018/849 amends Directive 2000/53/EC***, giving the Commission the power to adopt the following:

- implementing acts on the detailed rules necessary to control the compliance of EU countries with the objectives on ELV's and exports and imports of ELV's;
- delegated acts to complete the directive by:
- exempting certain materials and components containing lead, mercury, cadmium or hexavalent chromium (other than in the cases listed in Annex II), if their use is

unavoidable and establishing maximum permitted concentration levels, as well as deleting vehicle materials and components from the Annex II, if their use is avoidable;

- introduction of coding standards to facilitate reuse and recovery of appropriate components;
- establishing the minimum requirements for destruction certificates;
- establishing the minimum requirements for the treatment of ELV's.

Thus, the recycling measures in the development stage will be able to be implemented after the year 2020 when the cars will be able to be recycled in proportion to 90% because they will contain new design technologies that take into account very much the recycling process where the new cars will be subject to the future.

2.2 Responsibilities

The European Commission, through the Directorate-General for the Environment (DG ENV), proposes policies (including new legislation) and monitors the implementation of e-waste policy. The Commission can also launch infringement procedures against Member States when they do not comply with EU law. The European Statistical Office (Eurostat), another Directorate-General of the European Commission, is responsible for collecting data from Member States on electrical and electronic equipment (EEE) placed on the market, the collection/recovery of WEEE (including recycling and preparation for re-use), as well as on exported WEEE to perform consistency checks on this data. Eurostat also reports on the achievement of the WEEE recycling targets in the EU member states. [16]

Manufacturers and importers of electrical and electronic equipment used in the EU member states are responsible for checking the products introduced on the EU market in terms of compliance with the EU legislation in force and in terms of the financing and management of electronic waste resulting from the automotive industry.

If you manufacture, distribute or sell electrical and electronic equipment such as computers, fridges, mobile phones, EU and national laws require that you contribute to ensuring it is disposed of and treated properly. [17] This means:

- ***registering*** with the responsible national authorities ("registers") in each country where you distribute or sell equipment,
- filing a regular ***report*** on the amount of sold electrical and electronic equipment,
- ***organising*** or financing the collection, treatment, recycling and recovery of your products,
- as a distributor, providing a ***take-back*** service, whereby your customers can return electric and electronic waste free of charge,
- as a manufacturer, complying with the directive on the ***restriction of hazardous substances.***

2.3 EEE classification

Waste generated by such products is referred to as WEEE: Waste of Electrical and Electronic Equipment. It is known that an electrical installation defines a set of electrical equipment interconnected in a given space with a single, well-determined functional purpose.

So, by electrical equipment we mean any device used for the production, transport, distribution and use of electricity. Thus, electrical devices represent the totality of electro-mechanical device assemblies, as well as a category of electrical equipment, intended for command, protection, adjustment and automatic or non-automatic control of the operation of electrical installations in the automotive industry. They have the role of supervising and ensuring the normal development of electricity transport from sources to consumers.

2-4. Figure_ Car wiring tipe [https://soft-auto-bucuresti.ro/electrica-auto/]

The classification of electrical appliances can be done according to different criteria such as:

- nominal voltage;
- the type of current; the number of poles;
- operating regime;
- place of operation;
- the functions they perform, etc.

From the point of view of voltages and currents, two large categories are distinguished, namely:

- low voltage/high voltage devices;
- alternating current/direct current devices.

From the point of view of the number of poles, electrical devices are divided into:

- monopolar;
- multipolar (bipolar, tripolar).

From the point of view of the operating mode, devices with different operating modes are distinguished: long lasting; permanent; flashing; short-term.

From the point of view of the place where they work, electrical appliances are: for interior; external; encapsulated.

From the point of view of functions, electrical devices are classified into switching devices and protective devices.

Devices that allow some equipment of the electric power system to be put or taken out of operation, for example the separator, are switching devices. As a rule, the circuit breaker fulfills the role of a protective device, realizing the rapid interruption of the short-circuit current, which occurs in the fault mode.

Currently, 5% of the world's total municipal solid waste is e-waste, almost the same amount as all plastic packaging, but WEEE is much more dangerous. It is known that WEEE contains dangerous substances both for the environment and for the health of the population due to greenhouse gases or heavy metals that are harmful to health and the environment.

2.4 Environmental protection

After the Industrial Revolution, the world changed a lot, changing the conceptions, which led both to the achievement of significant progress but also to the achievement of some negative consequences such as environmental pollution [18]. After the 3rd industrial revolution, with the advent of today's electronics, later with interconnectivity and the personification of industry 3.0, 4.0 and 5.0, technological advances have been extraordinary, with change within everyone's reach. Waste obtained from electrical and electronic equipment containing toxic and environmentally hazardous materials, however, also contains valuable materials with high potential for recycling. [19] In general, in most cases these WEEEs end up directly in landfills, causing serious environmental and human health problems. [20] A small percentage of these (17%) end up being sent for recycling, which represents a minimalist percentage .

The automotive industry is one of the most important mechanisms of the global economy, but also one of the largest generators of hazardous waste. However, the production of motor vehicles and the provision of their maintenance services involve a large volume of waste. That is why many companies in this field opt for recycling in order to prevent blockages in the supply of raw materials and reduce the impact generated by this waste on the environment.

The lack of proper hazardous waste management leads to economic and biological imbalances that diminish the quality of life. That is why, in order to combat the pollution generated by the waste from the automotive industry, the authorities and environmental protection agencies draw attention to the importance of an environmental policy, which primarily aims at selective collection actions.

Waste management in the automotive industry involves the recycling and reintroduction of some waste (metal, oils, solvents, batteries, plastic and glass). Recycling these materials helps economic operators to address environmental concerns and solve the problem of resource depletion.

Much of this WEEE that ends up directly in landfills, in most cases, is composed of chemical substances, which improperly thrown into the environment, contaminates water, soil, groundwater, which further reaches living beings when they consume contaminated water, thus generating an abiotic environment. [21]

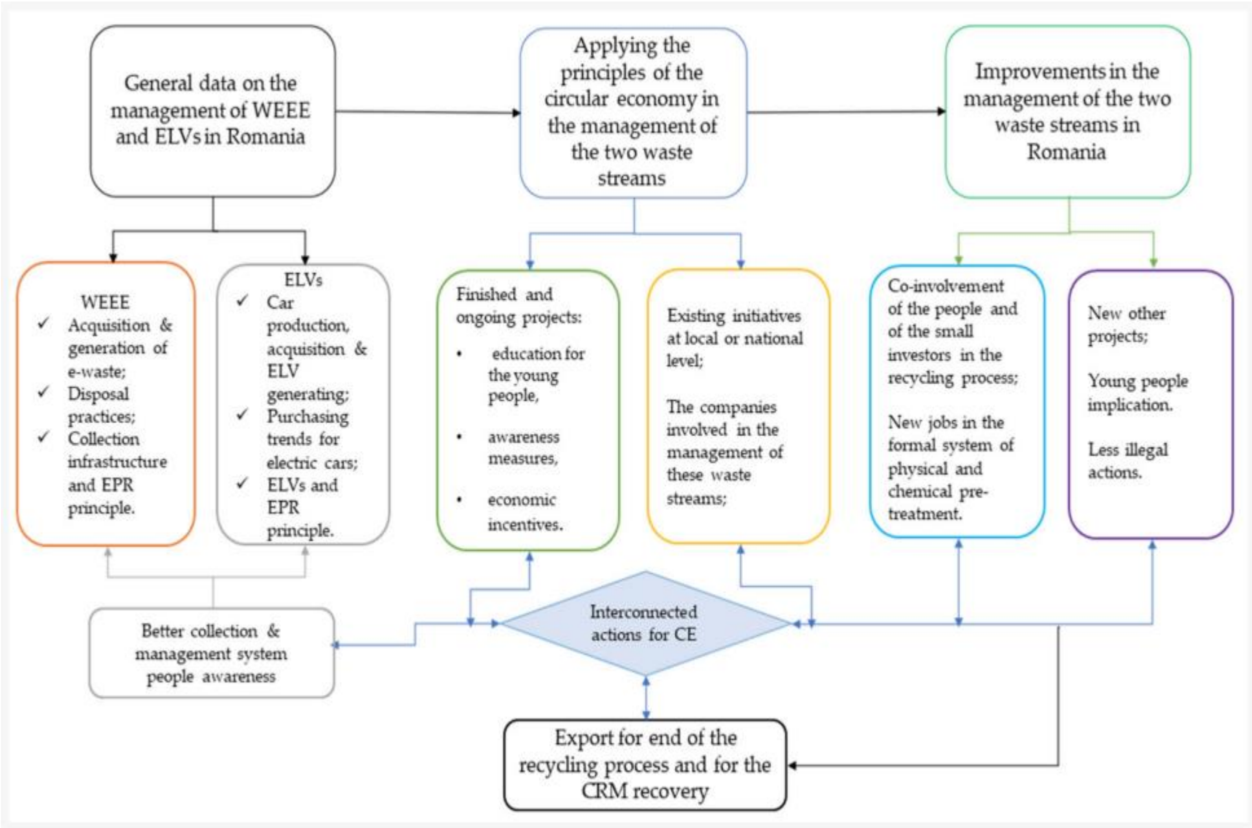
E-waste is defined as anything that requires electrical power that has reached the end of its useful life, as well as the components that make up these end-of-life products. Currently, only a few countries have a uniform way of collecting and recycling this waste. [22]

In Romania, the activity of collecting electrical and electronic waste from households has a well-defined route through their collection by private companies or through their collection by the municipality. Until the final destination, this waste undergoes a special treatment through which valuable materials are extracted in a controlled manner, managing hazardous substances and waste that goes to incineration or landfills.

For the more complex recycling activities, for which there is no available technology in Romania is preferable to export the by-products resulting from the collection and pre-treatment of e-scraps for the recovery of the critical raw materials (CRM) that they contain, by those who have the necessary technology and can ensure the conditions of protection of the environment and the health of the workers in the field.

In a broad sense, policies on the collection of WEEE from vehicles should increase the reuse and recyclability of all electronic parts, to lead to an extended life of products with lower energy consumption and to replace old vehicles based on fossil fuels with electric cars, motorcycles and electric public transport vehicles thus generating a biotic climatic environment.

E-waste circular business models must be supported to further catalyze such initiatives in other regions of Romania. The ELVs management practices are examined in line with auto industry trends in Romania and prospects of future investments in electrical/hybrid cars. This review points out the knowledge gaps and future research perspectives related to e-waste and ELVs under the circular economy framework.[8]



2-5. Figure_ Schematic representation of the study on the implementation of the circular economy (CE) in the management of WEEE and ELVs in Romania. [8]

Through rapid urbanization, there is also an increase in electrical and electronic waste, thus affecting the atmosphere with emissions of dioxins or furans, and the lithosphere and hydrosphere with the withdrawal of resources, causing environmental pollution and increasing dangers for human health. Through the intervention of the production chain, the life cycle of the materials that make up the EEE follows the steps of collection and dismantling. This recycling is carried out through the intervention of sustainable technologies, with the recording of information on the introduction, storage and recovery of metals and non-metals, thus bringing value to secondary matter.

Waste Electrical and Electronic Equipments (WEEEs) and End of Life Vehicles (ELVs) are two of the main waste streams, after municipal solid wastes, both in volumes and growth rates terms. Even if their management begins to be adequately regulated almost worldwide, there are still clear lacks to be solved in many aspects. The aim of this paper is the comparison, through a structured literature analysis, of these waste streams under several perspectives, by evidencing current differences and potential commonalities. In addition, a quantification of potential profits rising from a joined management of different sources of PCBs is described in the last part of the paper. [23]

The collection of WEEE aims to reinforce all the positive points of the previous routes by establishing a sustainable and intelligent technological route, based on the concept that EEE already incorporates IoT precepts. Thus, traceability and information to help structure sustainability, in addition to the technological innovations related to Industry 4.0, this technological route requires a reverse logistics, used the 3Rs (Reduce, Reuse and Recycle).

When these IoTs are introduced into the sensors of electronic equipment, they will give information about the different situations of WEEE throughout the life cycle of the product technologies, potentially helping with relevant information for recycling decisions. In this direction, the inputs from mining and the urban environment stand out, offering a management recycling of the shortage of renewable natural resources and the reduction of the stock of finite resources, known as virgin raw materials. From the generation of WEEE, it is possible to foresee the elimination, the adoption of internal procedures, the shared responsibility of both the producer and the consumer, or when these procedures do not exist, the latter being in non-compliance with the law.

Aspects relate to the reuse and recycling of WEEE, bringing social jobs in recycling industries or reuse cooperatives. In terms of economic aspects, there is greater productivity both in the production used Industry 4.0.

2.5 ELV's Recycling

Recycling emerged both as a new concept in the 20th century and as a possibility to limit waste and use resources more efficiently. It has become more and more clear that the automotive industry is growing in proportion to the growth of the population, thus leading to the consumption of ever greater amounts of resources from the automotive environment.

Directive 53/2000/CE (regarding end-of-life vehicles) stipulates the obligation of manufacturers to ensure at least free collection from the last owner of end-of-life vehicles and implicitly organize their treatment individually or through contracts with third parties.

This regulation aims, first of all, to prevent the production of waste from vehicles and, on the other hand, to reuse, recycle and other forms of recovery of end-of-life vehicles and their components in order to reduce the amount of waste destined for disposal.

The main recyclable resources regarding their recovery and reuse represent means of solving the contradiction between the process of economic growth and the restrictive character of resources.

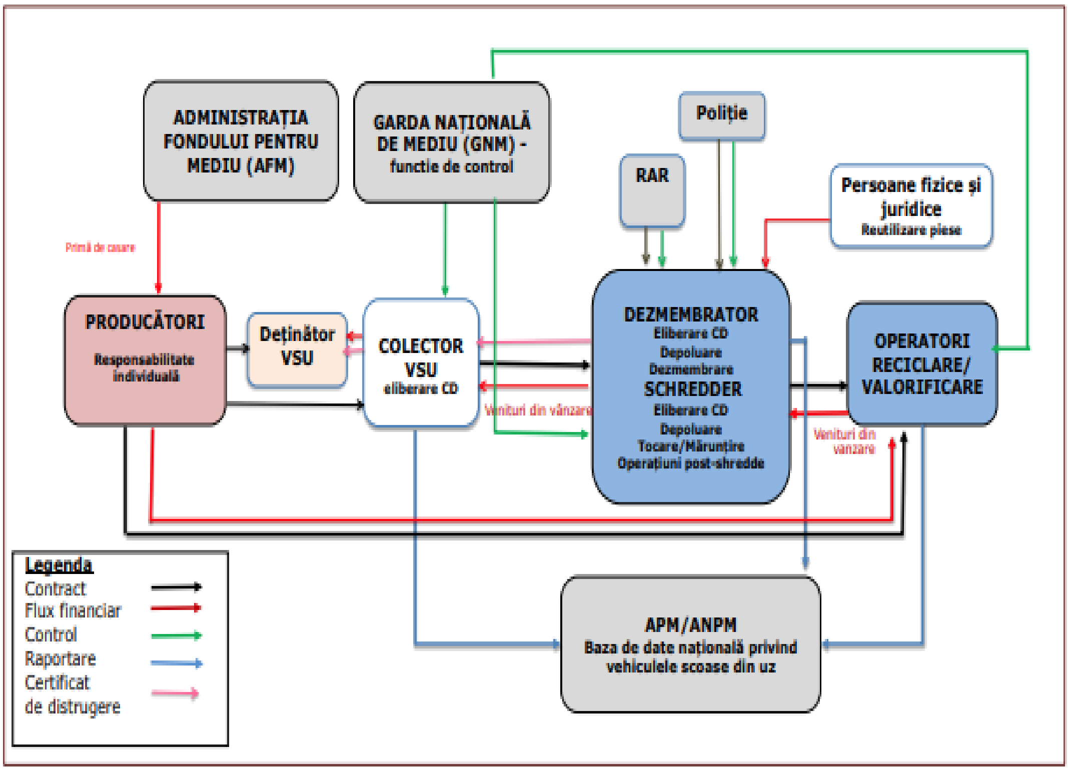
"Waste electrical and electronic equipment" (WEEE, "electronic waste" or "waste electrical equipment") is "various forms of electrical and electronic equipment that no longer have value to their users or no longer serve their original purpose". This includes a whole range of devices, from mobile navigation systems and IT equipment to small equipment such as power window systems or tire pressure monitoring systems. This waste does not include car batteries, which in the EU are regulated by separate legislation.

In 1998, Romanian car manufacturers set out to increase the recycling rate for new cars to 90% from 75%. Currently, in Romania, extended producer responsibility is applied for ELV's, but only in the individual system. The producers have chosen to establish collection networks through private contracts with authorized dismantlers, where, in accordance with the provisions of Law no. 212/2015 on the way of managing vehicles and end-of-life vehicles, handing over to the ELV's treatment facility and taking over the vehicle from the last owner should be free. [24]

In practice, the ELV's holder collects a sum of money when the ELV's is handed over to the collector or dismantler. The exception is ELV's handed over under the "Rabla" program, for which the holder receives only the voucher related to the "disposal premium", no other amounts.

Consumers who buy parts resulting from the dismantling of the ELV's pay for them to the dismantling companies. Also, recyclers pay the dismantlers or shredders the value of the secondary raw materials resulting from the ELV's treatment.

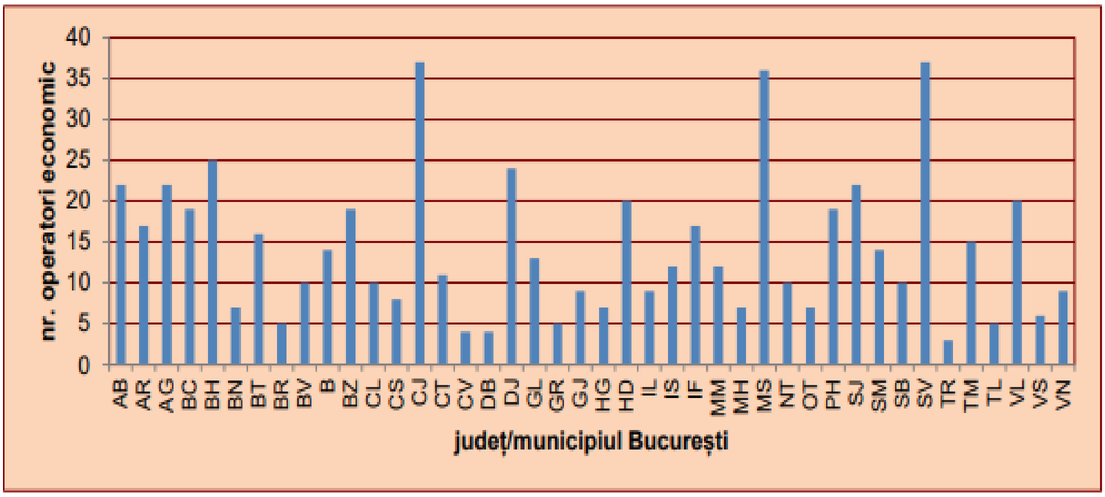
For materials sent for energy recovery or co-processing in cement plants, we have no information that there are any financial costs or benefits. We encounter the same situation with the waste resulting from chopping/shredding.



Source: The National Waste Management Plan (PNGD)

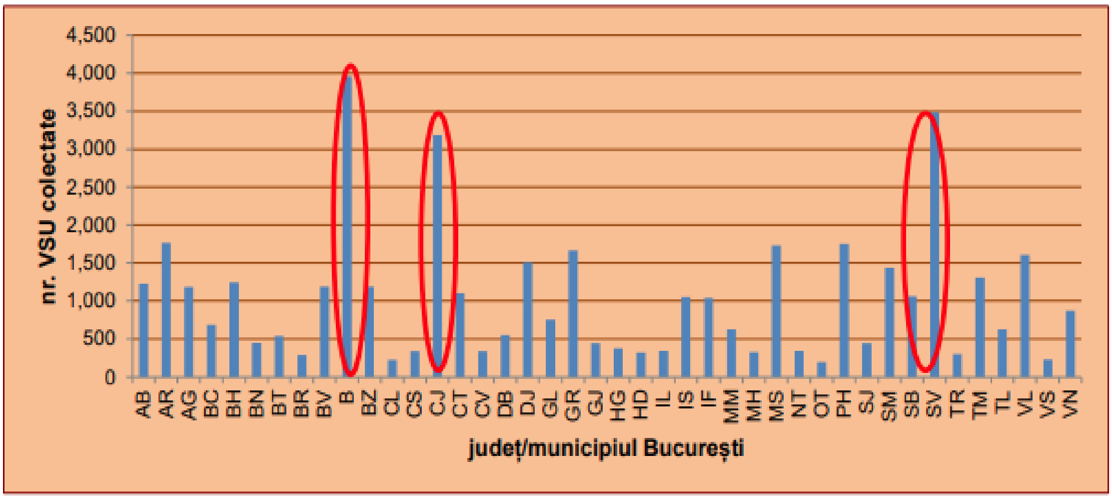
2-6. Figure_ ELV's management scheme with operational and financial responsibilities

Currently, at the level of Romania, 608 economic operators are authorized that are active in the field of collecting and/or treating ELV's. Of these, 545 have environmental authorization for the ELV's treatment activity and 4 economic operators own shredders, according to PNGD.



Source: MAPN

2-7. Figure_ Distribution of economic operators authorized for the collection of ELV's



Source: MAPN

2-8. Figure_ Distribution of the number of ELV's collected by county and Bucharest

From the analysis of the graphs above, it can be seen that in the counties where a greater number of ELV's are collected, there is also a greater number of collectors. The exception is the Municipality of Bucharest, where there are only 14 authorized collectors. However, the ELV's treatment capacity in the city of Bucharest is ensured by two high-performance and high-capacity shredder installations. The S.C. REMATHOLDING Co S.R.L. facility in Bucharest with a capacity of 1,000 t/hour to which is added, a first for Romania, a shredder residue treatment facility, with five sorting steps, of which a sand sorting step is the first installation of this kind in Europe. Another shredder facility in Bucharest is the one owned by S.C. ROMRECYCLING S.R.L. In addition, two shredder installations operate, both owned by S.C. REMATINVEST S.R.L. in Cluj and Timiș counties. (according to PNGD)

In the ELV's shredding process, the shredder residue (consisting of glass, rubber, textiles, cables and plastic) can constitute more than 25% of the total weight of the ELV's entered into the shredder campaign. (according to PNGD)

Household manufacturers are obliged by GEO 5/2015 to take care of the collection and collection of end-of-life products, unlike car manufacturers who have so far avoided a restriction, openly promising that they will collect end-of-life equipment by autonomous means.

The difference between the two industries is not very clear, but one explanation would be that the number of car manufacturers is not very large, therefore they would not deliberately violate a decision of their own.

The lightness in terms of legislation is nevertheless beneficial, because being forced, car manufacturers prove to be much more efficient with their own recycling measures.

Thus, *the recycling measures* in the development stage will be able to be implemented after the year 2020 when the cars will be able to be recycled in proportion to 90% because they will contain new design technologies that take into account very much the recycling process where the new cars will be subject to the future.

Recycling measures after the abandonment of motor vehicles are the most studied of all because the most important objectives to be achieved will be:

- Disassembly of the machines should be as easy as possible;
- Development of disassembly companies;
- Components remaining after recycling should be as few as possible;
- Development of own design technologies for car manufacturers.

The intense concern for both manufacturers and society led to a cooperation between the various disassembly companies. 10 years ago, the price of scrap metal was so high that the business would have been quite profitable. Now, however, the price of products has fallen so much that it is almost impossible to recover the cost of recycling just by selling scrap metal and other materials.

If there was a market for used parts, any disassembly company could sell these recycled products and the business would be very profitable. Under these conditions, some of such companies have developed their outlets in other countries in order to survive, these companies may in the future start collecting money from car owners.

Another serious problem is the construction of a disassembly flow, which is quite difficult to achieve.

The fundamental principle for the development of waste electrical and electronic equipment (WEEE) policies/laws/regulations is based on their conceptual life cycle, thus the main element in any policy/law/regulation is the definition of WEEE/E-waste to be regulated.

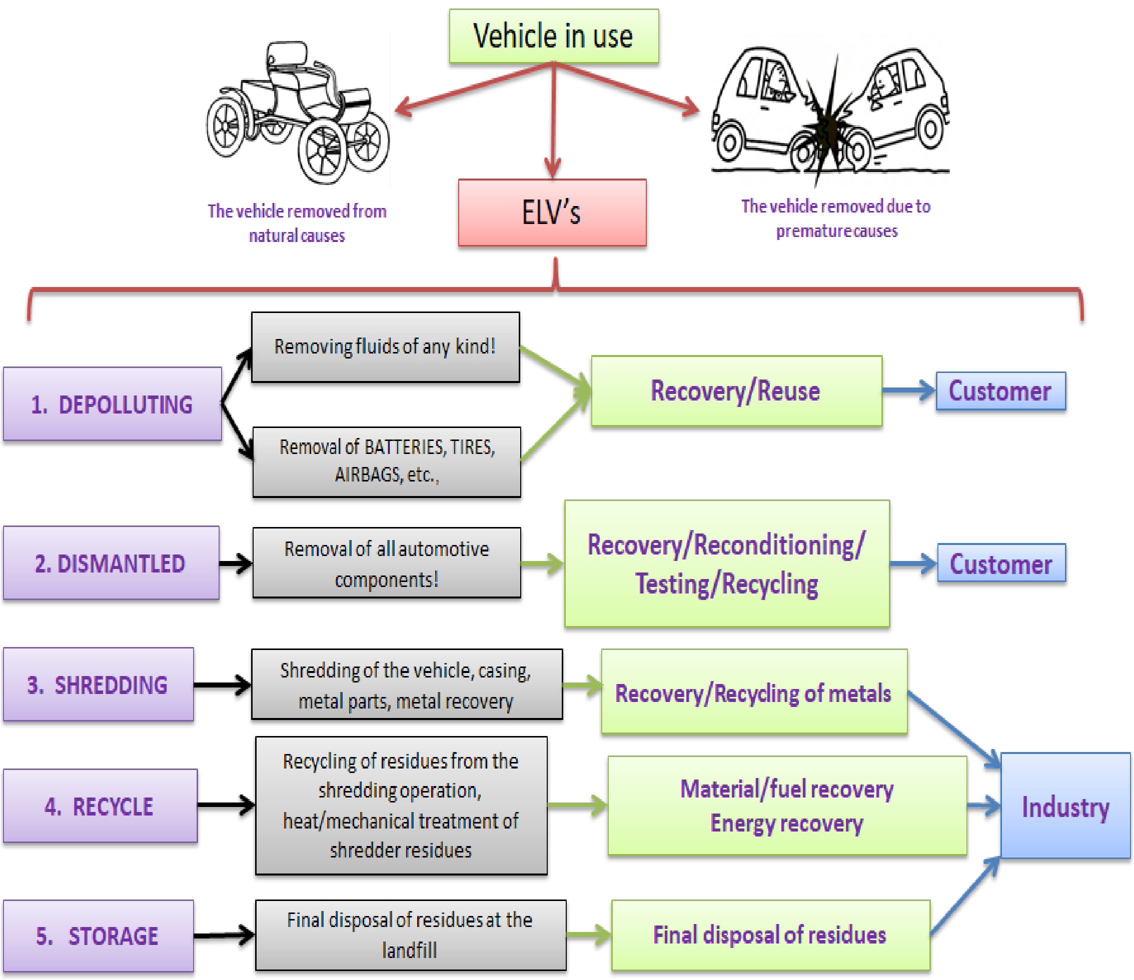
Globally, WEEE/e-waste are the most commonly used terms for e-waste. There is no standard definition for WEEE/E-waste. The most widely accepted definition of WEEE/E-waste is that according to the EU directive, and this is followed in the member countries of the European Union and in other European countries.

The statement CLEPA – Weuropean Association of Automotive Suppliers – Brussels, 04/07/2018, on the applicability of ELV vs RoHS / WEEE in the automotive industry, helps companies to define which directives apply to the parts to be recycled, either the ELV directive or the RoHS/WEEE directive. [25]

2.6 RECYCLING PHASES

End-of-life vehicle recycling involves the processing and preparation of used vehicles for disposal which requires six different activities, as shown in the next figure:

1. Delivery and storage of old vehicles for recycling;
2. Depollution by removing hazardous fluids and materials from vehicles
3. Dismantling vehicles for usable or recyclable parts;
4. Crushing or shredding vehicle bodies;
5. Sorting of materials into ferrous materials, non-ferrous materials and other residues;
6. Recycling of metal fractions.



2-9. Figure_ ELV's recycling phases

1. For a vehicle at the end of its life cycle, the first step is to hand it over to an authorized dismantler. Thus, the last owner of the used vehicle will deliver it to an authorized dismantler, who, after checking the vehicle, will issue a Certificate of Destruction necessary for the cancellation of the vehicle.

2. The first step in ELV's recycling is Vehicle Decontamination and Pretreatment which involves removing all fluids, fuel and any potentially hazardous components such as batteries and airbags. This includes: engine oil, transmission oil, brake fluid, as well as coolant from the air conditioning system.

3. Then Disassembly and removal of all recyclable parts such as tires, catalytic converter, etc., as well as removing the hybrid battery for electric vehicles. Materials such as plastic or glass are stored separately for recycling.

4. Storage of materials harmful to the environment with a view to separate collection and subsequent delivery to companies specialized in their recycling, to be recovered or disposed of.

5. Shredding or shredding, the pre-treated parts are sent to a shredder (Shredder) that cuts the end-of-life vehicle into pieces in order to sort it into different fragments for further recycling or recovery.

6. Post-shredder Technologies of Material Sorting, where previously cut materials are further processed through various technological sorting processes (magnetic separation, eddy current, flotation) to obtain new material fragments that can be used as secondary raw material with value, with a view to re-introduction on the market or in the industry.

7. Recycling / Recovery / Storage. The residues obtained from the sorting of materials can be recycled (as a substitute for blast furnace coal, as a dewatering agent for conditioning liquid sewage residues) or can be recovered and introduced into the cement industry.

This chain of technological processes leads to a 90% recovery of the vehicle drastically reducing the amount of waste left for the landfill.

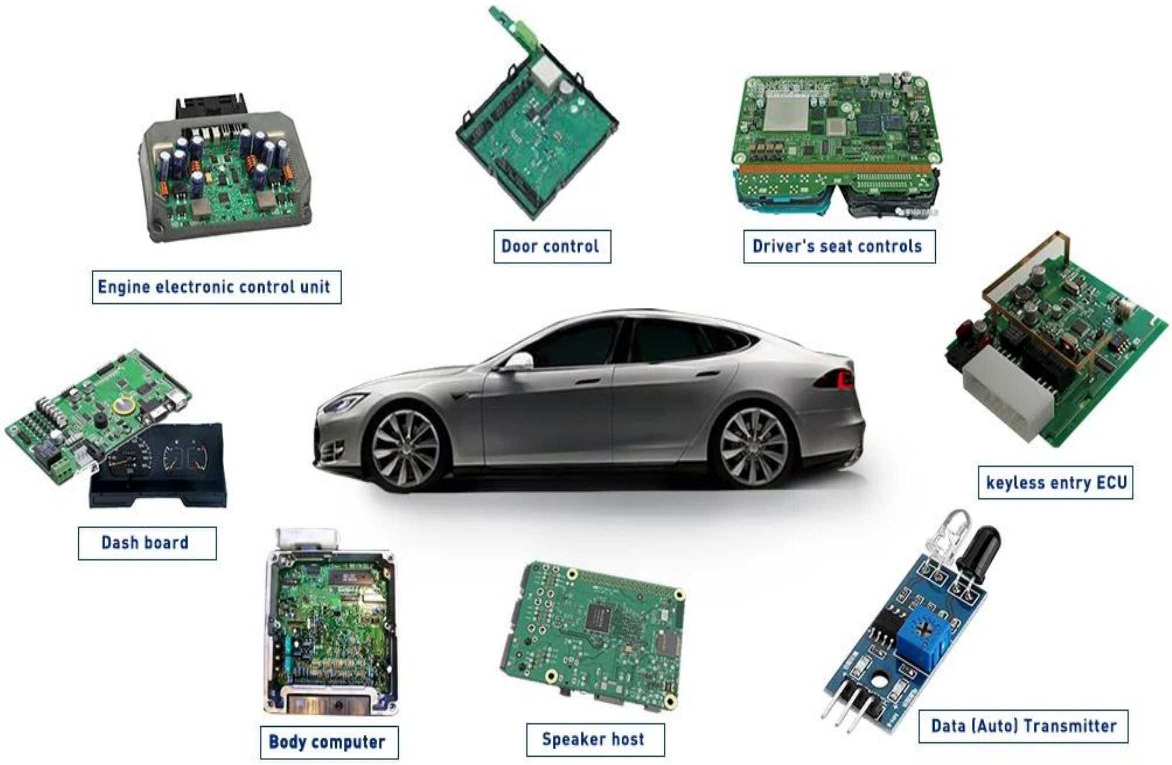
2.7 Common point between WEEEs and ELVs

End-of-life vehicles (ELVs), together with waste electrical and electronic equipment (WEEE), are known as an important source of secondary raw materials. For many years, their recovery has allowed the restoration of large quantities of metals for the production of new cars. Thus, the automotive sector becomes a relevant source of WEEE, given the even more relevant presence of electronic components in cars. Due to new European environmental policies, the volume of end-of-life vehicles (ELVs) is expected to increase in the near future, along with electronic components obtained from obsolete vehicles.[10]

A modern mid-size car incorporates on average up to 15 electronic components (up to 50 components in luxury cars). Since 2000, electronics has had an increased opening in the automotive sector. A report quantified the automotive microcontroller market at approximately USD 989.2 million in 2017, with a projection to USD 1886.4 million by 2022, at a compound annual growth rate (CAGR) of 13.8% [26]. Of note is the low interest of car manufacturers in recovering these valuable electronic components from end-of-life vehicles (ELVs).

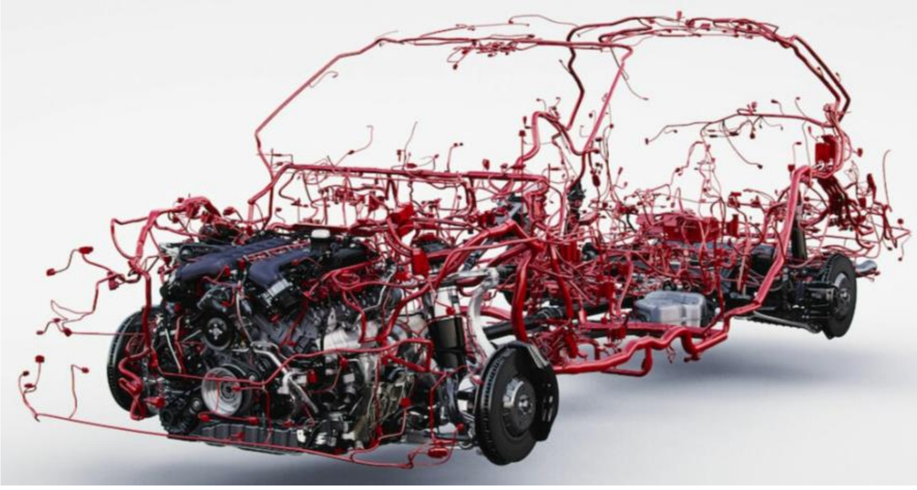
Currently, there are still many problems to be solved to functionally recover materials from end-of-life (ELVs) cars, for example the reuse of recovered materials for similar purposes to the manufacture of new cars (even if they work electrically/ hybrid/fuel). Solving these problems requires a mandatory systemic transformation by redefining the life cycles of machines, starting from the design phase.

A common point between WEEEs and ELVs is represented by PCBs (**Waste printed circuit boards)**. Recent works verified that scrap automotive PCBs are, in effect, very similar to PCBs coming from e-wastes. After the monitors and on-board computers have been disassembled there is a group of six PCB categories.



2-10. Figure_ Types of PCBs after disassembly of waste on-board computers and monitors [https://www.kingfordpcb.com/vehicle-electronics/]

If, for example, the wiring harness needs to be removed, the vehicle has to be very much 75% dismantled. During the manufacturing process of a vehicle, the wiring harness is one of the first components to be assembled into a vehicle. Insulation, carpets, seats, instrument panel, consoles, covers and trim are installed after wiring. During the dismantling process it is thus one of the last parts to be removed from the vehicle. In addition, the wiring of a vehicle is very branched, therefore, removing the wiring means completely disassembling the vehicle - a very complex and time-consuming process.



2-11. Figure_ Wiring location (red), on car model [https://www.carscoops.com/2022/05/carmakers-are-rushing-to-adopt-simpler-modular-wiring-harnesses/]

The ability to efficiently collect and recycle WEEE in order to reduce the impact on the environment and recover the resources they contain requires the combined involvement of all the actors involved, namely producers, retailers, PRO organizations, local authorities, the population who are the final users of EEE, all possible collection channels for total or partial reuse, recycling and appropriate recovery of WEEE.

Raising public awareness of reuse services and the benefits of reuse should be prioritized, highlighting and correctly reporting reused WEEE is very important. The reparability of WEEE should be taken into account by providing reparability from the EEE design phase (green design).

Modern cars also contain an important part of electronic products, including integrated circuit boards. Although the collection streams are separate, as are the public policies for e-waste and WEEE, they have similarities, both due to the content of similar resources, especially metals, and the inclusion of a wide range of electronic products in modern cars.

On the other hand, since this waste has on the one hand a hazardous potential and on the other hand a high residual value for the monitoring of e-waste flows, there is a more specific sub-indicator of this waste, as a ratio between generated and recycled e-waste.

Table 1. Characterization of mass electronics PCBs

Material	Cat1 (%);	Cat2 (%);	Cat3 (%)
Silver (Ag)	0.02	0.17	0.08
Gold (Au)	0.002	0.04	0.01
Copper (Cu)	11.0	20.0	17.25

The characterization of PCBs has been implemented in a different way in the automotive field because the wastes obtained from automotive PCBs are very different in terms of size, shape and composition depending on their functionality.

Table 2. Characterization of automotive PCBs

Material	Cat1 (%)	Cat2 (%)	Cat3 (%)	Cat4 (%)
Silver (Ag)	0.09	0	0	0
Gold (Au)	0.42	0.20	0.24	0.09
Copper (Cu)	18.84	24.19	14.52	16.30

Comparing the two tables, we can confirm that the material composition of PCBs embedded in WEEE and ELV is not so different. The only difference lies in the quantities of materials (eg precious metals), with a large impact on the profitability of the recovery process.

PCBs, as already defined at the beginning, are the most important link between WEEE and ELV. Given that these are the two main sources of waste worldwide, they can also automatically be considered the two main sources of PCB waste. Their volumes are impressive and comparable. In fact, even though PCBs represent a limited percentage of the total weight in both WEEE and ELV (3% - 6% and 0.1% - 0.7% respectively), their volumes are quantifiable in terms of kilotons per year.

Obviously, the growth rates directly follow those predicted for both WEEE and ELV by several experts. For example, in the EU28 these volumes can be accounted for in approximately 167 Kton/year and 17 Kton/year for WEEE and ELV, respectively, considering the forecasts for 2015. These impressive amounts of PCB volumes, together with the percentage of valuable materials incorporated into them.

Another topic that, after PCBs, better connects WEEE and ELVs concerns **hybrid and electric vehicles**. In fact, these types of cars, which are becoming even more common on our streets, have a high presence of electrical and electronic equipment embedded in a vehicle, with a high use of valuable and critical materials (for example, precious metals of the group – PGMs in PCBs), rare earth elements – REEs in electric motors and batteries, aluminum and magnesium in frames. Thus, once the car reaches the end of its life, these vehicles could become a very important source of materials.

This phenomenon is quite studied and some companies have already implemented models of dedicated recovery stations (especially for recycling batteries). However, as in other industrial areas, recovery targets are still very limited as there are no current regulations or directives on the recycling of WEEE in the automotive industry.

Even though PCBs are recognized as the most important component of electrical and electronic waste from motor vehicles, there are no explicit regulations regarding their treatment. The directives speak of them as hazardous components (such as batteries, airbags, capacitors, fuels, filters, etc.) to be treated separately from the main e-waste and

ELV recycling process, but there are no details on specific recovery levels which must be collected at authorized centers.

The physical characteristics (e.g. material layering, component miniaturization, current safety regulations) of PCBs limit the chances of recovering 100% of the materials, and much of it is unintentionally lost during mechanical treatments, heating phases or chemical reactions.

Common technologies used to treat PCBs are taken from the mining sector. In this way, their focus is on optimizing quantity (rather than quality) and recovery rates hardly exceed 20% - 30% of input materials.

Given the current directives, there are no limitations on the export of PCBs from one European nation to another. Thus, local resources that could be kept within national borders (with positive effects for the overall local industrial context) are transferred abroad.

2.8 The 3Rs of WEEE

The 3Rs: ***Recovery, Reuse and Recycling*** of electrical and electronic equipment from the automotive industry are a major problem not only at the national level, we can even say at the world level. Even in large industrialized countries, only a part of this electronic waste is subject to recovery and recycling, others being thrown into the landfill or, depending on their type, are incinerated.

RECYCLE

The world has become smarter and better at recycling, helping to reduce the demand we make for the world's natural resources and the amount of waste we generate.

REDUCTION

By reducing the materials, resources and energy we need to build a car, we can reduce our impact on the environment.

REUSE

We are finding more and more ways to reuse items and resources, reducing the demand we make for raw materials, saving energy and contributing to environmental protection.

On the other hand, a good management of WEEE will greatly contribute both to the implementation of environmental policies and to the uncontrolled disposal of waste being a real danger, but at the same time it will promote the saving of resources and raw materials. The adoption of EU regulations in the field, although it has been achieved and continuously implemented in Romania, regarding the collection of electronic waste there are still many aspects to improve.

The recycling of WEEE from the automotive industry is the most complicated type of waste due to their compositions and toxic substances that can harm the environment while also endangering human health. WEEE/E-waste is a complex mixture of hazardous and non-hazardous waste from all end-of-life electrical and electronic equipment that used batteries or mains, requiring specialized collection, sorting, transport, treatment and disposal phases.

Thus, by definition according to Romanian Emergency Ordinance 5/2015, *"WEEE represents all equipment that operates on the basis of electric current or electromagnetic fields, but also equipment for the generation, transport and measurement of these currents and fields, which are intended for use at a lower voltage of 1000 volts alternating current and 1500 volts direct current are hereinafter referred to as Electrical and Electronic Equipment (EEE)".*

3 WEEE RECYCLING PROCESSES

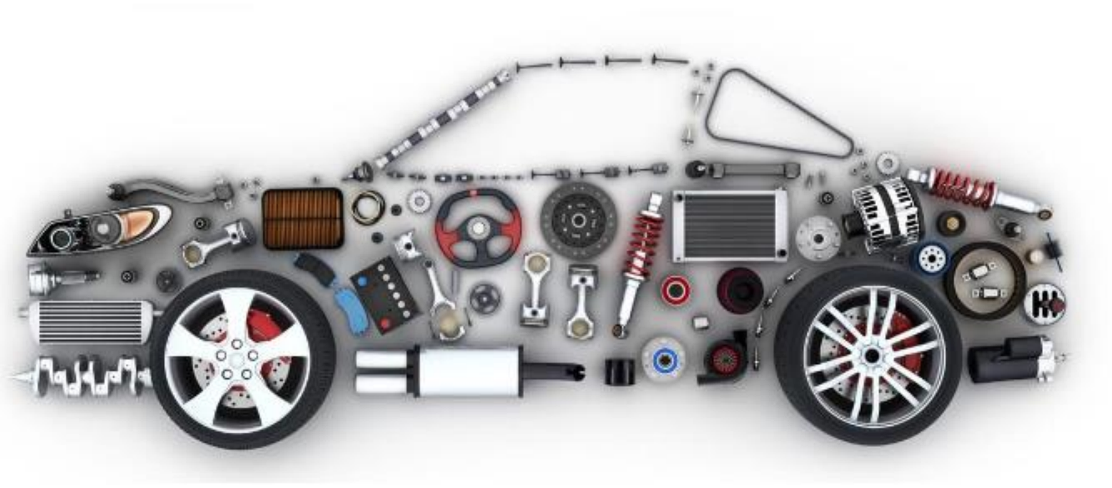
When talking about end-of-life vehicles, it is important to remember that the most manageable waste is the waste that is easy to obtain. Thus, redesigning vehicles for a greener environment, including their longevity, repairability and recyclability, enforcing and improving existing laws, and researching better recycling technologies can also help to reducing the collection of waste obtained from end-of-life vehicles.

In the last years, the world has become smarter and better at recycling, helping to reduce the demand we make for the world's natural resources and the amount of waste we generate.[27] Thus, returning products, materials and resources back into the product cycle at the end of their use can thus help reduce import dependencies and supply risks.

We recognize the great value of recycling that helps us protect the environment, by reducing our demand for natural resources and by reducing the amount of waste we generate, which cannot be used beneficially. The design of our vehicles should be done using parts and materials that can be reused, whether they are reprocessed for use in manufacturing, recycled or used in a completely different way, for example, as an alternative energy source.

According to European legislation, we need to make sure that our vehicles are at least 85% recyclable and 95% recoverable, but we are moving forward to make this process as simple and efficient as possible. All car manufacturers should use initiatives such as parts marking and active cooperation with specialist partners to discover even better ways to recycle the vehicles of the future.

3-1. Figure_ Vehicle recycling process [https://vahanrecyclingindia.com/services/]



3-2. Figure_ Vehicle dismantling point
[https://cashforcarswhangarei.co.nz/auto-parts-dismantlers-of-all-makes-models/]

Thus, according to the laws in force, from January 1, 2015, a percentage of 85% of each vehicle must be reused or recycled, and 95% recovered. From an end-of-life car, through recycling, a number of elements can be reused, from the leather and textile materials used for the upholstery, to the steel present in the body. All of these are mainly reused by the automotive industry. In fact, it is currently estimated that recycled metals make up about 25% of the amount needed to make a new car. Therefore, car waste plays an important role in the development of the high-performance models currently on the market.

Furthermore, we can say that the process of recycling car waste is a very complex and necessary process in order to reduce the impact on the environment.

3.1 Easte collection

In our country, the measures to prevent the production of waste from end-of-life vehicles and the collection, reuse, recycling, as well as other forms of valorization of them and their behavior, in order to reduce the amount of waste intended for disposal, are regulated by GD no.2406/21.12.2004 regarding the management of end-of-life vehicles. [28]

In order to prevent waste, vehicle manufacturers, in collaboration with component and material manufacturers, will take the necessary measures to:

- ***Limiting and reducing*** as much as possible the use of hazardous substances in the construction of vehicles, starting from the design phase, in order to avoid environmental pollution, facilitating the recycling of components and materials, as well as avoiding the disposal of hazardous waste;
- ***Designing and building new vehicles***, taking into account the possibilities of disassembly, reuse and valorization of their components and materials;
- ***Development of the use of recycled materials*** in the production of new vehicles or other products.

Vehicle manufacturers and manufacturers of components or materials have the obligation to code the components and materials to facilitate their identification during disassembly for reuse, recovery, recycling. Manufacturers, in collaboration with the economic agents involved in the management of end-of-life vehicles, are obliged to publish in the technical book or through other means of information information regarding the disassembly, storage and testing of reusable components.

Individuals or legal entities keeping end-of-life vehicles have the following obligations:

- **not to abandon end-of-life vehicles** or their solid and/or liquid components, on the ground, in the surface waters and the territorial sea;
- **to hand over end-of-life vehicles** to economic agents authorized to carry out collection and/or treatment activities of end-of-life vehicles.

3-3. Figure_ ELV's collection [https://www.colectareautorable.ro/]

Vehicle manufacturers must ensure, individually or through contracts with third parties, the takeover from the last owner of the vehicles they have introduced on the market, when they become end-of-life vehicles. Vehicle manufacturers are also obliged to provide collection points in each county or in different cities, depending on the number of inhabitants.

The economic agents authorized for the collection of ELV's are obliged to issue a certificate of destruction to the last owner of the vehicle, upon taking it over. in case the economic agents only carry out collection activities, the destruction certificates will be issued in the name of the treatment units with which they have a contract, with their written consent and in compliance with the legal provisions in force.

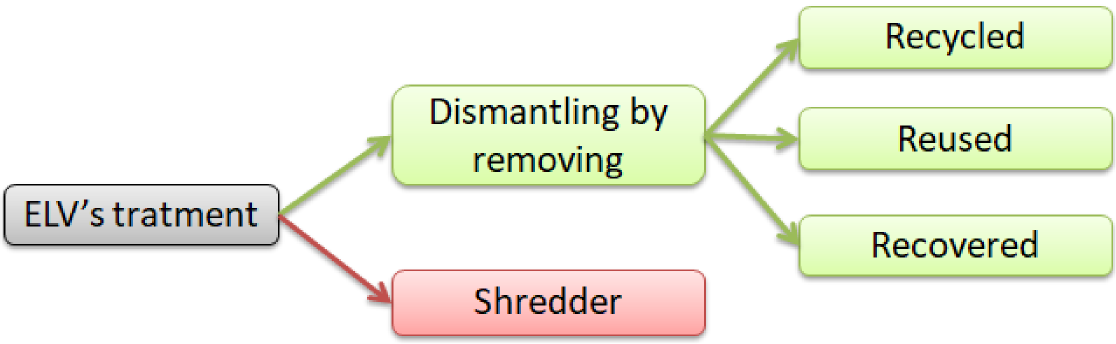
Vehicles end up in the category of end-of-life vehicles, end-of-life vehicles (ELV's), for two reasons:

- aside from the fact that they reach a certain ***"age",*** they practically become ***"old***", they are called "***natural end-of-life vehicles***";
- or they suffered accidents as a result of which they could no longer be recovered, the latter bearing the name of "***prematurely retired vehicles***".

The treatment of ELV's can be done either by ***dismantling***, by removing the component parts that can be recycled, reused or recovered, or sent directly to the shredder

("shredder"). Regardless of which of these two methods, ELV's will pass through the first phase through a depollution stage.

Although, in the past, vehicles could reach the shredder whole, with the increase in the requirements contained in Annex I of Directive 53/2000, it is necessary to remove materials such as glass, tires, materials intended for recycling, in addition to preliminary depollution stage These new restrictions will encourage an increase in the number of ELV's that will be subject to dismantling rather than shredding.



3-4. Figure_ The treatment of ELV's

The disassembly process will identify parts that can be reused, such as the engine, battery, alternator and steering system. Liquids, gases and other materials and parts will be safely collected and, where appropriate, recycled. Disassembled metal bodies are often compacted and sent for shredding.

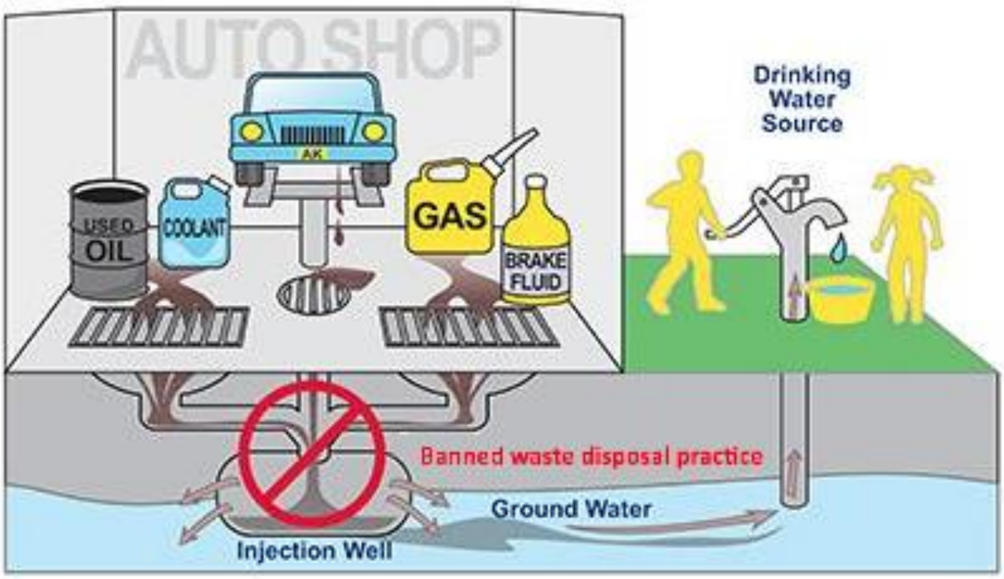
After this process, different types of metal can be extracted for reuse, leaving only a relatively small amount of residue. To encourage responsible and efficient vehicle disposal, authorized dismantling centers have been established in Europe where vehicles can be taken for recycling.

3.2 Depollution and dismantling

The first step of the recycling process is depollution. This involves removing all fluids, fuel and any potentially dangerous components such as batteries and airbags. Next, all recyclable parts are removed, such as tires and catalytic converter. Disassembly continues with the removal of the hybrid battery. In the case of the Prius Plug-in, the battery is lithium-ion, using the same type of power technology as a smartphone or laptop battery.

Removal of fluids

After the inventory, the fluids are extracted and disposed of in accordance with the legislation in force.



3-5. Figure_ EoL car depollution
[https://www.epa.gov/uic/motor-vehicle-waste-disposal-wells]

Disposing of end-of-life vehicle waste by improper disposal can seep into shallow groundwater and contaminate nearby drinking water sources. Thus, it is recommended that the depollution of these vehicles be carried out in special recycling and dismantling centers that ensure compliance with the legislation in force regarding environmental pollution.

These centers have waste removal systems (pits) from floor drains or sinks where various author components are washed using various solvents. Thus, any septic system in which liquid waste from motor vehicles is collected is considered to be a disposal well for motor vehicle waste.

During normal vehicle repair and maintenance, fluids such as engine oil or solvents leak or spill into floor drains or sinks in service areas. Liquid waste from motor vehicles includes:

- Engine oil
- Transmission fluid
- Power steering fluid
- Brake fluid
- Antifreeze
- Coolant from the air conditioning system
- Solvents
- Degreasers

If these fluids are not disposed of properly, through an automotive waste disposal well, they can contaminate groundwater. Therefore, the EPA regulates these wells to prevent groundwater contamination in licensed auto service areas.

Removal of hazardous parts

Recycling reduces the amount of waste from warehouses that is harmful to the environment, so the process of depollution of the vehicle at the end of its life also includes the process of removing parts that contain dangerous substances: BATTERY, TIRES and AIRBAGS.

The hazardous wastes from the depollution of EoL vehicles, is:

- **Car batteries** often contain lead and other chemicals that can contaminate the environment if disposed of in a landfill. Many car shops have the possibility to send the old batteries back to the manufacturers or to the recycling centers for their safe disposal. Some of them are in good condition and completely reusable.
- **Tires** are non-degradable, so they take up a lot of space in storage places if they are not recycled. If they are burned, the environment is polluted by the release of toxins into the air and they produce a flammable rubber leak. Tires removed in good condition can be reused on other vehicles or transformed by retreading or retreading into new tires.
- **The airbag** [29] is one of the vital safety features of a car that has saved many lives over time. Car airbags are part of the vehicle's additional safety system. They have been around since the 1970s and are now standard equipment on every vehicle since the 2000s being mandatory on all automobiles as an essential safety measure.

The airbag is a rather complex system, but it works extremely easily. That is, it is a piece composed of two elements, the balloon that inflates and the quick release system. The airbag is connected to a computer equipped with several sensors that sense the moment when the car is involved in an accident big enough to endanger people's lives, at which point the airbag is triggered.

The deployment of the airbags is done through an action that lasts only a fraction of a second. From the first moment of impact, when the sensor feels the shock in the body, it triggers a pyrotechnic clip that ignites some granules that burn instantly, producing the **gas** that inflates the balloon. It is not a capsule with compressed air, but a gas that is produced on the spot, in a fraction of a second. Obviously, the gas that inflates the cushions called airbags is not harmful and does not cause burns.

For some reason, there are customers for second-hand airbags from dismantled cars, so they can be bought both new and from dismantled ones. Second-hand airbags are practically new, they are airbags that have never been activated, but from used vehicles.

3.3 Dismantling

It is important to ensure waste collection infrastructure that could also ensure a sustainable market for secondary raw materials. Prompt and effective measures in this regard would have a direct impact on the management of waste, including e-waste and end-of-life vehicles, their repair and reuse, the recovery and recycling of the resources contained therein, as well as the reduction of their environmental impact and impact on human health.

While cars already contribute to the increase in pollution in congested cities, some of their components can be reused in other cars. Furthermore, considering the current evolution of transportation towards hybrid and electric technologies with self-driving systems, their major growth is expected in the coming decades.

3-6. Figure_ Dismalting
[https://www.dezmembraripieseauto.com/articol-reciclarea-autovehiculelor]

To encourage responsible and efficient vehicle disposal, authorized dismantling centers have been established in Europe where vehicles can be taken for recycling. Over 80% of the weight of the entire vehicle is reused, re-manufactured or recycled. Thus, after the removal of fluids and hazardous materials, the components that can be recycled will be identified, such as:

Bodywork: vehicle parts and general steel products are obtained;

Body and mechanical parts that are in proper condition are sold as replacement parts for collision repair and mechanical repair facilities. Unusable parts are recovered as scrap and the metal is recycled.

Glass: reused as spare part if recovered intact or as raw material for cement;

Electrical cables and wires*:* copper products are obtained, motors (cast aluminum armature);

Radiator (contains Copper and Aluminum): Bronze ingots and aluminum products are obtained;

Engine: reused as a spare part if functional or recycled to obtain aluminum products;

Catalytic converter: reused as a spare part if recovered intact and functional or recycled;

Transmission: Recycled into general steel and aluminum products;

Tire: Recycled to produce raw material for cement and heat source. Quality tires with a long life are sold for reuse. Others are sent to tire recyclers and processed to make new products. Thus, tires are often shredded and broken down into pellets before being reused as soccer field flooring or to pave highways.

Wheel: Recycled into vehicle parts, general steel products and aluminum products. Wheels are sold for reuse. In some cases, they are reconditioned, and the damaged ones are recovered as scrap metal.

Suspension: recycled to obtain general steel and aluminum products;

Chair: recycled to obtain raw material for cement and the heat source;

Metal bodies that can no longer be used for the purpose for which they were designed are disassembled and often compacted and sent for shredding.

After this process, different types of metal can be extracted for reuse, leaving only a relatively small amount of residue.

3.4 Sorting metal

The upward trend in recent years in the production of waste electrical and electronic equipment (WEEE) is due to a wide range of utilities. One part of WEEE is fundamental to almost all equipment: printed circuit boards (PCBs). PCBs have a metallic fraction with mostly iron, copper, nickel and precious metals, for example gold, and a fraction of non-metallic products.

Fiberglass is part of that non-metallic fraction of PCBs, it can be used to replace a small part of the ore materials used in the production of many compounds. The recovery process of these fibers is an organic one, where organic solvents are used to separate the fiber layer without contaminants.

Fibers recovered through this process can be included in the manufacturing process of casting compounds. Casting compounds, especially those based on epoxy resin and bulk, are thermoset polymers reinforced with glass fiber to be used in many different fields (building and construction, automotive, mass transport, electrical, sanitary, household and many other sectors).

The use of recycled materials in the manufacturing processes of various composites is becoming more and more important as mineral materials are increasingly scarce. Due to their characteristics, the recycling of these thermosetting polymers is difficult, so it may be more advantageous to include recycled materials, such as recovered fibers, in the production process.

To each molding compound made using epoxy resin and bulk resin, three possible formulations are proposed: one with the partial use of long fibers, another with powder fiber mixed with fiberglass, and one with the full percentage of long fibers from WPCB. To evaluate the influence of using WPCB fibers, mechanical tests were performed: flexural, tensile, and Charpy impact. Recycling cables has been a profitable business for decades, as wired copper and aluminum from old cables can be recycled again and again. [30]

Cable recycling is the process of cutting the cables and sorting the metal from the insulation for recycling. The most sought after resources are copper and aluminum. Achieving these steps requires quality machines for profitable cable recycling, whether the input is dry cables, ACSR cable, wiring wires, gelatin filled cables, greasy underground cables, etc. The modular design allows the facilities to be expanded or upgraded with market changes, i.e. by adding a primary shredder to increase capacity, a classifier to clean the plastic fraction to avoid metal loss, etc.

The automatic circuit board waste disassembly equipment is composed of circuit board waste disassembly machines and waste gas treatment equipment, used to disassemble the electronic components on the circuit board, because different components contain different metals (some components contain gold, silver , palladium and other precious metals), while some components contain toxic substances. Some components can be sorted and sold directly. The disassembled base plate is also easier to break and separate the copper, which greatly reduces the work of the crushing and sorting section and improves the recycling rate of precious metals. [31]

3-7. Figure_ Downsizing cables and sorting metal / Raw material finished product [31]

3-8. Figure_ Flow chart [31]

Automatic circuit board disassembly equipment melts the tin from the board by heating it and then uses rolling friction to separate the electronic components from the motherboard. In this process, exhaust gases are absorbed by activated carbon to treat formaldehyde and then water is sprayed to precipitate the exhaust gases.

Features of automatic disassembly equipment:

1. Fully automatic operation, two people are enough;

2. Performs removal and disassembly of components in one process, temperature automatic and controlled by heating system;

3. Large capacity: 300 kg/h, 500 kg/h,

4. Less component damage, precious metals can be recovered without too much loss;

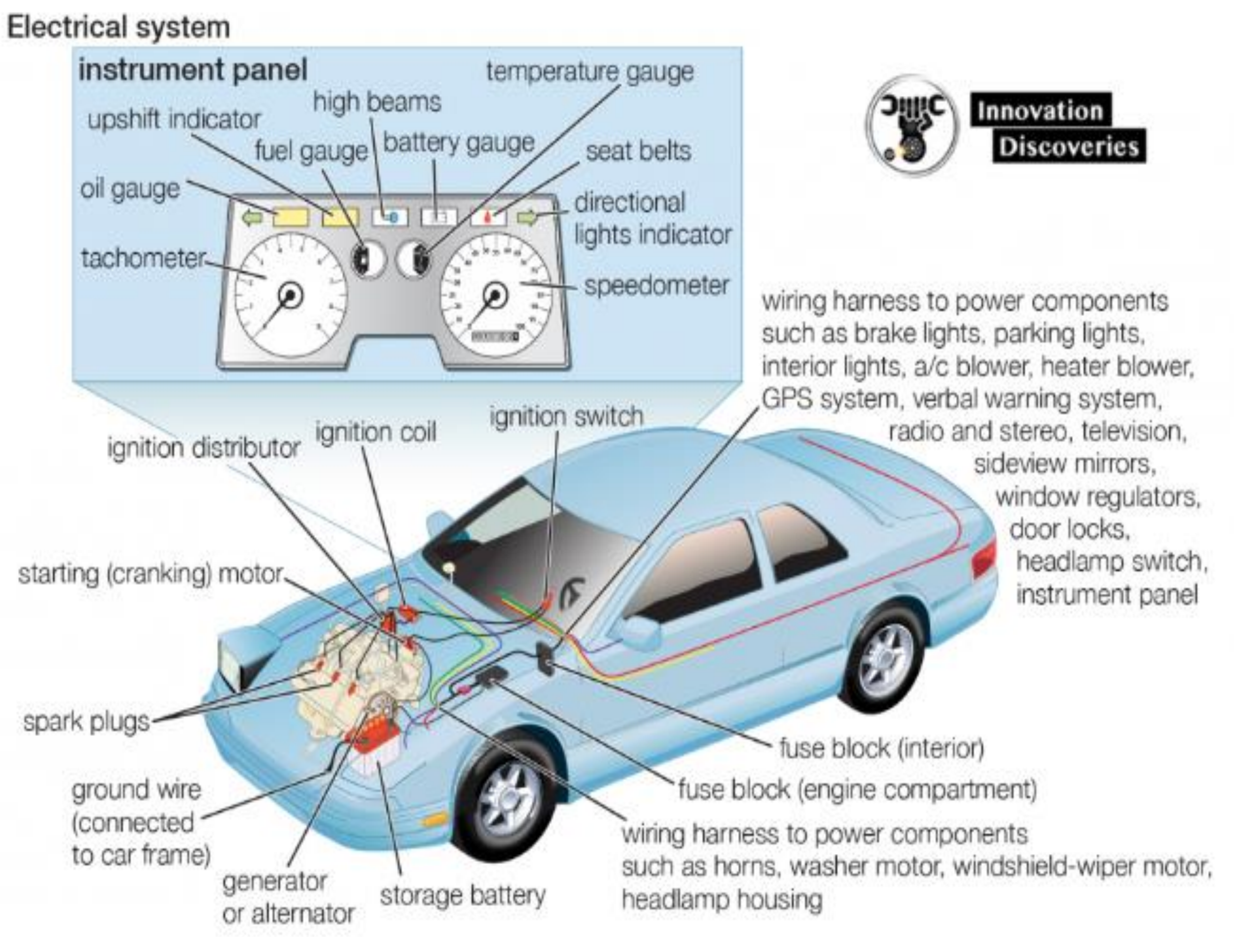
5. The motherboard and components can be processed and reused in various environments to bring economic benefits;

6. Environmentally friendly.

3.5 Electronics device recycling

Electronic device recycling or e-waste recycling, electronic and electrical waste, WEEE – whatever you call it, is a growing opportunity for recyclers around the world as the amount of waste and the need for resources increases.

In order to know what the electrical and electronic parts and equipment of an ELV's are, we must first know how the electrical system of a car works. Thus, the car's on-board network is the car's power network that connects the sources and consumers of electrical energy. The sources of electrical energy in the on-board network are a generator and a storage battery (battery).



3-9. Figure_ Automotive electrical system diagram [https://innovationdiscoveries.space/how-car-electrical-systems-work/]

Consumers

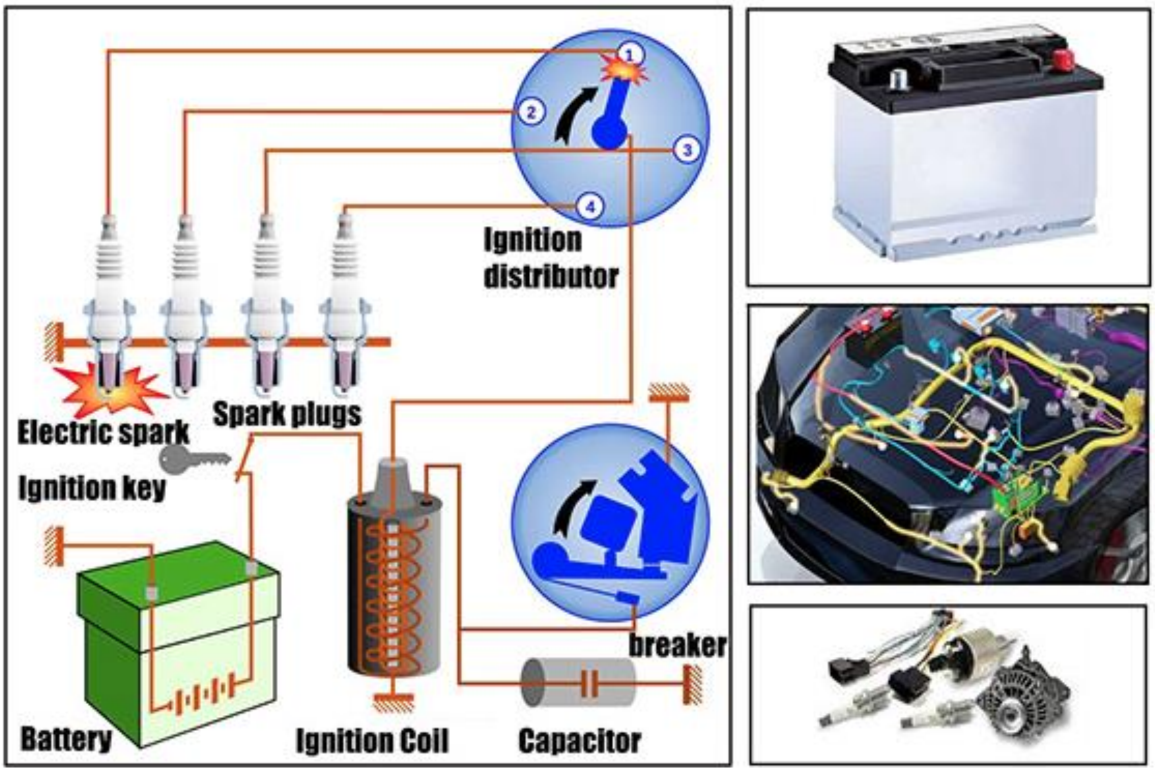
The main car electricity consumers:

- Storage battery by the charging;
- Field Generator ;
- Car Ignition system;
- Headlights and sidelights of a car;
- Alarm;
- Fans, heated seats and windows;
- Car`s audio system;
- Switching, distribution and protective devices;
- Fuse holder;
- Buttons, switches and switches, relays;
- Switching and power blocks;
- Car wiring.

Car electrical system

The electrical system of a car is designed to generate and transmit electrical energy to various electrical and electronic systems and devices of a car, it includes the following components:

1. current sources,
2. current consumers,
3. control elements and
4. electrical wiring.



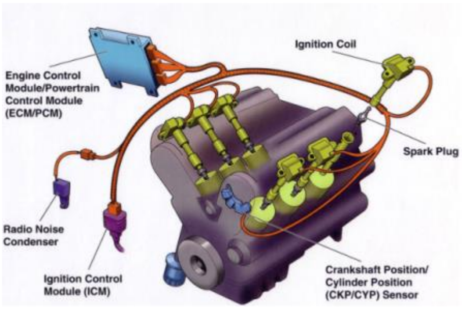
3-10. Figure_ Car's electrical system
[https://www.newkidscar.com/electrics/how-a-cars-electrical-system-works/]

All these components of the electrical system are connected to a single "vehicle network."

1. ***Power supplies*** are the main components of a car's electrical system. The battery provides the initial power while the generator maintains the charge. They provide power to the various systems and devices of the car to run smoothly and efficiently. These sources being: **Battery and Generator.**

2. ***Current consumers*** are the starter that starts the engine, the headlights that illuminate the road, and the air conditioner that needs energy, all these devices require a certain amount of energy. All these devices include the following car systems:

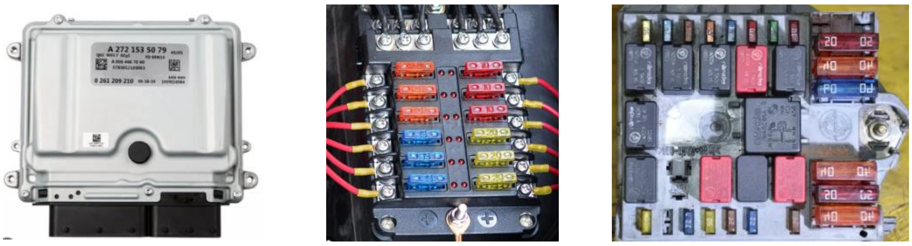
- The ignition system is used to create and deliver a spark discharge to the spark plugs of an internal combustion engine. There are three types of ignition systems: with contact; no contact; microprocessor based.
- The engine starting system is responsible for starting the engine by creating a certain rotational speed of the crankshaft.
- The lighting and signaling system consumes electricity and ensures the operation of the front and rear lights, indicators, fog lights and clearance lights. The control and measurement tools ensure the control of the technical parameters of the vehicle's operation and allow the driver to monitor them.



3-11. Figure_ Ignition system in petrol engines [www.autoexpert.ro]

3. ***Control elements*** are the control devices that ensure the coordinated operation of the car's on-board system. These devices include:

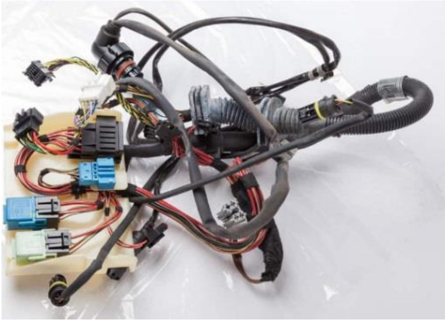
- Electronic Control Units (ECU) – a central control unit and control units for individual units such as the engine, suspension and braking systems.
- Fuse boxes.
- Relay blocks.



a) ECU; b) Fuse boxes; c) Relay blocks.

[www.auto.ro]

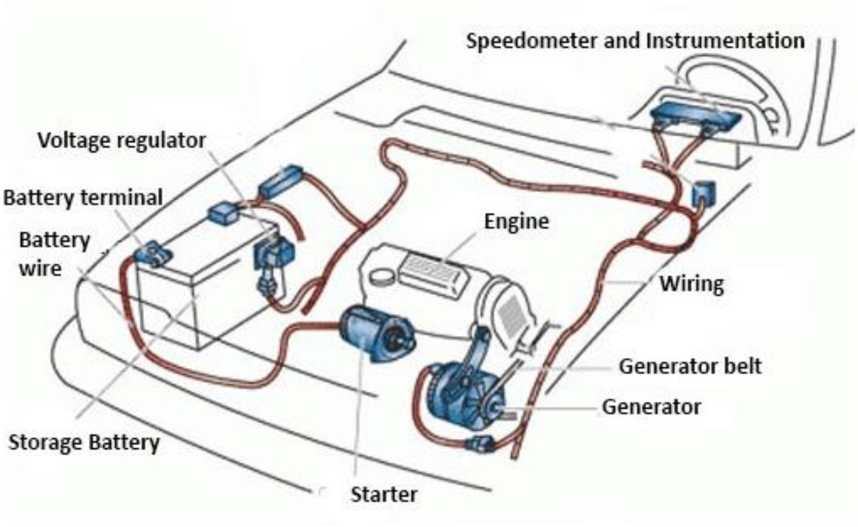
4***. Electrical wiring.*** There are single-wire and two-wire electrical wiring schemes. In a single-wire scheme, power is supplied through a single positive wire, and the body of the car serves as the neutral. In a two-wire scheme, the negative wire is connected to the ground at the closest point. Connectors Mounting block, fuse block. Multiwire cabling.



3-12. Figure_ Multiwire wiring [www.wiringo.com/automobile-wire-harness.html]

Wiring harness

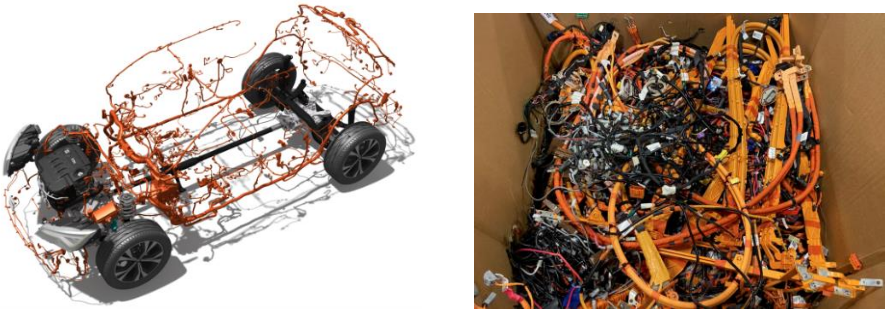
Automotive electrical wiring consists of copper wires with different sections, being insulated with a special plastic insulation that prevents them from overheating and igniting. The cables are bundled and placed on the car body (body) in special places. Insulating tapes and clamps can be used to fix the cable bundle. In the engine compartment, the electrical wiring is inserted into corrugated or molded plastic tubes. For speed and easy recognition, the wiring varies in color depending on the belonging to certain devices. Color coding is done to improve troubleshooting and simplify vehicle maintenance. Marking and color coding is applied by the manufacturer.



3-13. Figure_ Vehicle electrical system construction [https://www.newkidscar.com/electrics/how-a-cars-electrical-system-works/]

During the manufacturing process of a vehicle, the wiring harness is one of the first components to be assembled into a vehicle. If, for example, the wiring harness needs to be removed, the vehicle has to be very much 75% dismantled. Insulation, carpets, seats, instrument panel, consoles, covers and trim are installed after wiring. During the dismantling process it is thus one of the last parts to be removed from the vehicle. In addition, the wiring of a vehicle is very branched, therefore, removing the wiring means completely disassembling the vehicle - a very complex and time-consuming process. [32]

Cars have been evolving with increasingly complex circuitry. SEAT's Ateca crossover (SEAT is a Volkswagen Group company, the Ateca is based on the MQB platform and is related to Volkswagen's Tiguan) for example, features a complex arrangement of wires more than 2.2 km long.



3-14. Figure_ Wiring location [https://www.greencarcongress.com/2019/02/20190224-ateca.html]

The ability to efficiently collect and recycle WEEE in order to reduce the impact on the environment and recover the resources they contain requires the combined involvement of all the actors involved, namely producers, retailers, PRO organizations, local authorities, the population who are the final users of EEE, all possible collection channels for total or partial reuse, recycling and appropriate recovery of WEEE.

Raising public awareness of reuse services and the benefits of reuse should be prioritized, highlighting and correctly reporting reused WEEE is very important. The reparability of WEEE should be taken into account by providing reparability from the EEE design phase (green design). Modern cars also contain an important part of electronic products, including integrated circuit boards.

Although the collection streams are separate, as are the public policies for e-waste and WEEE, they have similarities, both due to the content of similar resources, especially metals, and the inclusion of a wide range of electronic products in modern cars.

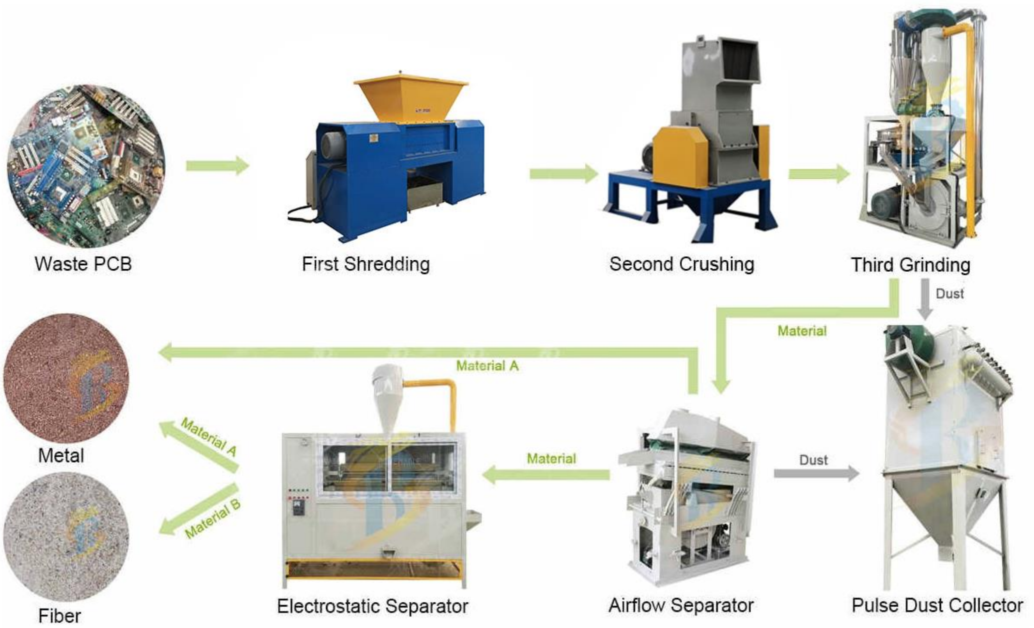
Electronic recycling is the process of reducing various types of electronic and electrical waste to release metals and separate them from organic materials such as plastic and rubber for reuse. The most sought after resources are ferrous and non-ferrous metals such as ***aluminium, brass and copper***, as well as the precious metals ***gold and silver***.

3-15. Figure_ Electronics recycling [https://www.pinterest.com/]

The DEEE waste recycling plant is suitable for recycling motherboards, copper clad boards, PCBs, mobile phone boards, etc., to recover the non-ferrous metals of ***copper, gold, silver, palladium, platinum and rhodium*** from these wastes.

The entire equipment separates the copper and resin from the circuit board by physical crushing. At the same time, the equipment is also equipped with impulse dust removal devices to effectively solve the dust generated in the production process. The subsequent use of high voltage electrostatic sorting machine makes the sorting more fine and efficient because it effectively controls the loss of non-ferrous metals and the metal sorting rate reaches up to 98%.

3-16. Figure_ Raw Materials/ Final Product



3-17. Figure_ Flow chart [https://www.sunymachine.com/NEWS/119.html]

The advantages of the recycling process:

1. Compact structure, reasonable appearance, stable performance, low noise.

2. The baseboard waste recycling equipment adopts two-stage crushing, which can make the processing capacity reach 800kg per hour.

3. The whole production line adopts negative pressure feeding to effectively reduce dust overflow.

4. Airflow sorting rate is up to 97%.

5. The high-voltage electrostatic separator makes sorting finer and more efficient, effectively controlling the loss of non-ferrous metals.

6. The iron can be separated from the material by the magnetic separation function.

7. The motherboard waste recycling equipment adopts PLC to control the whole production line.

8. The grinding chamber adopts circulating water temperature control and noise reduction.

9. The return system makes crushing more efficient.

10. The efficiency of pulse dust removal equipment is up to 99%, which effectively inhibits dust volatilization.

3.6 Precious metal recovery

The precious metal recovery and refining plant is used to extract precious metals such as gold, silver, palladium and platinum from electrical and electronic components, and the purity of extracted precious metals can reach 99.99%. The raw materials are mainly from scrap circuit boards, computer processor, motherboards, VCD, CD, TV, telephone, mobile communication and others.

Reclaimable materials also remain from the electroplating plant, the electronic component plant, the photosensitive plant and the electronics plant.

3-18. Figure_ Flow chart precious metal recovery [https://www.alibaba.com/]

Advantages of the metal recovery process:

1. Distribution of gold pickling solution;

2. The surface coated materials are placed in the liquid, then the surface gold is dissolved in the gold pickling solutions. No other metal such as lead, nickel, iron or any other metal will dissolve in this solution.

3. Filtration to remove impurities;

4. Reduction: Add the reduction powder to the solutions, the gold will be extracted and turn into black powder, let the black powder settle, then we finally get the raw gold powder.

Features of the recovery facility:

1. After processing, wastewater emissions remain the same;

2. The recycling rate of gold, chips, platinum, palladium can reach more than 97-99%;

3. The purity of the precious metal can reach 99.99%;

4. The equipment is fully automatic, saving labor cost;

5. The process is short, the use of cyanogen-free hydrometallurgical technology reduces environmental pollution.

3.7 Cooler recycling

The CFC/pentane gases that are used in old refrigerators are very harmful to the atmosphere, which implies a special configuration of the recycling process.

Refrigerator recycling is the process of reducing the size of refrigerators to collect harmful gases and sort solid materials for recycling. The most sought after materials are ferrous and non-ferrous metals. Complete refrigerator recycling solutions include everything from reduction and separation to oil and gas collection in an inert process.

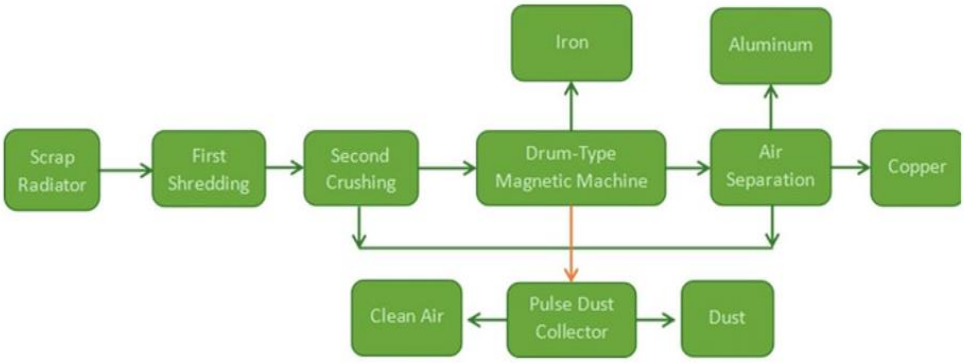
Recycling facility for old radiators

The radiator waste recycling plant can handle all kinds of large block radiators, such as air conditioner radiator, car radiator, radiator waste recycling equipment by biaxial crusher, magnetic belt separator, dust remover with pulses, air separator, PLC control system, the whole device by physically crushing the copper and aluminum radiators in the separation.

The whole recycling line is controlled by PLC program, equipped with automatic stop and automatic overload alarm device.

The successful development of the processing line greatly frees up productivity, improves the quality of metal reuse, and at the same time reuses the advantages of iron, especially in the treatment process, effectively solves the dust overflow by reducing air pollution.

3-19. Figure_ Raw Materials / Final Product



3-20. Figure_ Flow chart [https://www.sunymachine.com/MM/Radiator-Recycling-Machine.html]

The radiator waste recycling plant adopts the recycling method of fragmented physical separation, in which the material is put through the biaxial shredding machine to achieve a coarse crushing, then it is transferred to the crusher room and ground to 3 cm size, then through magnetic separation of iron and air classifiers more efficient sorting is achieved. Through this process, an effective control of non-ferrous metal losses is achieved and the metal separation rate is up to 98%. At the same time, the dust generated in the production process is effectively solved by the impulse dust removal equipment.

Advantages of the recycling facility:

1. The whole production line adopts PLC control, ensuring the stability of the equipment operation.

2. Simple structure, reasonable appearance; high processing capacity, stable operation; durable, safe and reliable.

3. The shredder adopts two axes of double roller design, with advantages of low noise, high torque and large crushing chamber, etc.

4.The shredder adopts tool steel, made by special processing technology, with wide application ranges, combines extrusion cracking, breaking and crushing. It is easily applied to the chopper of various raw materials.

5.The magnetic separation equipment adopts powerful magnetic drum separator, with a sorting rate of 99%.

6. Pulse dust removal system to suppress 99% dust overflow efficiency, no secondary pollution.

7. Using the air flow sorting machine, with a sorting rate of 97%.

3.8 Car battery recycling

Every year the evolution of electric vehicles grows exponentially due to the need to meet the global objectives of reducing GHG emissions to combat global warming.

According to the Paris Declaration on Electric Mobility and Climate Change, where a target was set for at least 20% of vehicles globally to be electric vehicles by 2030, it is estimated that the energy storage system in batteries will increase by 25 % per year, which makes sourcing materials or elements needed for the manufacturing process such as lithium, cobalt, graphite, manganese and nickel very cumbersome and expensive. Thus, for the recycling of these, new recycling, treatment and disposal technology will be needed to avoid pollution problems and to establish economic sustainability because EoL EV batteries can have a negative impact on the environment being composed of toxic chemicals and materials dangerous. If managed improperly, they will release pollutants into water, air and soil.

The most common battery recycling technologies are hydrometallurgical, pyrometallurgical or direct recycling. To date there are no international standards for disposing of waste in a unified, ecological way that can be adopted globally.

LIBs have been developed for energy storage for the transportation sector and renewable energy systems. Basically, a LIB consists of two cell electrodes, an anode and a cathode, and the main source of active lithium ions in a battery is the positive electrode (cathode). Based on the cathode materials, LIBs can be classified into different types such as [33]:

- Lithium Cobalt Oxide ($LiCoO2$)-LCO;
- Lithium Manganese Oxide ($LiMn2O4$)-LMO;
- Lithium Nickel Oxide ($LiNiO2$)-LNO;
- Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO2$)-NMC;
- Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO2$)-NCA;
- Lithium-ion Phosphate ($LiFePo4$)-LFP;
- Lithium Titanate ($Li4Ti5O12$)-LTO (negative electrodes).

Health impact.

Material	Human Health Impact
Copper	High concentration of Cu leads to cardiovascular, immune and nervous system risks
Graphite	High concentrations of graphite flakes produce carcinogenic toxicity for humans, affecting the respiratory system, but also physical-mechanical damage to the skin and unprotected eyes.
Plastic	have a negative impact on body function and increased risk of disorders and diseases
Cobalt	Inflammatory lung, allergic skin reaction, etc.
Aluminum	Al toxicity causes harm to the brain system, bone marrow, and osteomalacia
Lithium	High concentrations of Li cause toxicity to human cardiomyocytes, and itcan affect hematopoietic stem cell differentiation and glycogen synthesis during fetal development, etc.

Iron/Streel	Particulate matter of Fe leads to risks of cardiopulmonary diseases and stroke and increased vulnerability to inflammation-associated pathologies such as respiratory diseases and lung cancers
Manganese	Mn nanoparticles can access the brain, causing damage to neurological syndromes, such as Parkinson's disease
Nickel	Ni chronic exposure in the body has adverse negative health effects in humans, such as lung fibrosis, renal disease, cardiovascular disease, and respiratory tract cancer
Electrolyte	Electrolytes of LIBs usually include both organic solvents and inorganic solutions, can cause corrosive skin burns, eye damage, and produce hazardous gas, leading to respiratory systems

Source: adapted after Noudeng V,et.al, 2022

The recycling of car batteries, especially the recycling of Li-Ion batteries, is necessary to ensure the recovery of limited resources and for substances harmful to the environment to be collected and disposed of or reused safely. Especially since the number of electric cars is increasing worldwide, so will the need to recycle Li-Ion batteries.

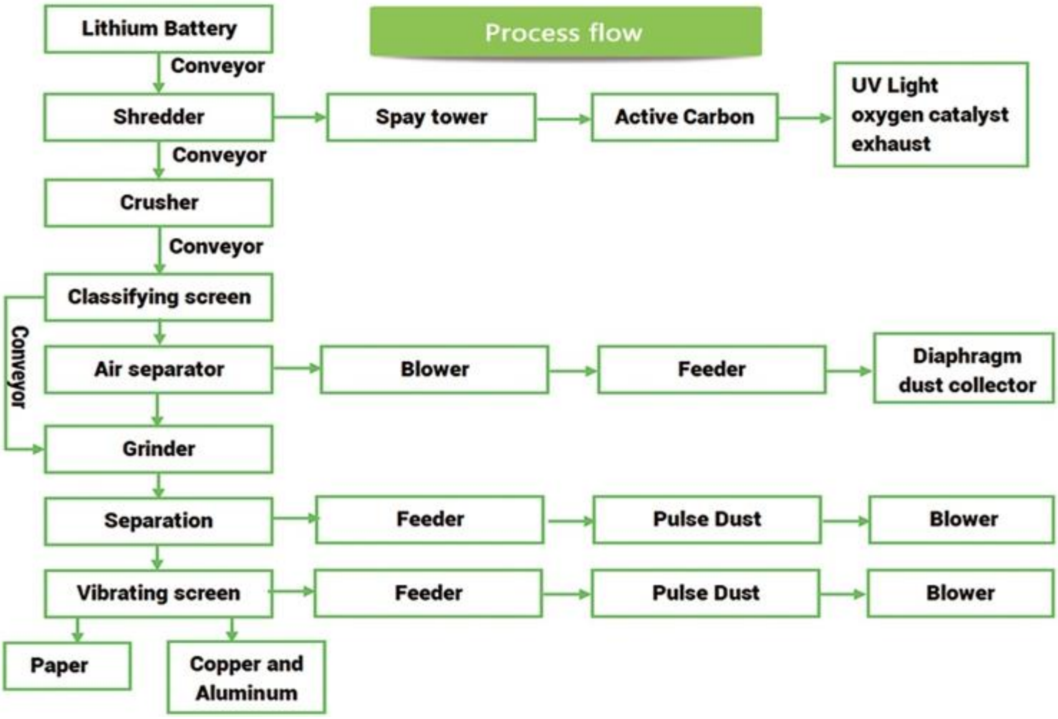
Car battery recycling is the process of reducing car batteries to collect harmful substances and sort solid materials for recycling. The most sought after materials are different metals.

3-21. Figure_ Electric vehicle battery tipe [https://timesofindia.indiatimes.com/]

At present, the research on the recycling of waste lithium batteries is mainly focused on the recovery of high-value anode precious metals cobalt and lithium. Copper in the negative electrode of waste lithium battery(content up to 35%) is an important production raw material widely used Carbon powder adhered to it can be used as additives such as plastics and rubber. Based on the structural characteristics of lithium batteries, an environmentally friendly physical separation process must be adopted to achieve the efficient separation and recovery of lithium battery waste.The lithium battery recycling production line is used for dismantling and recycling the Soft package battery, cellphone battery, Shell batter Cylindrical battery etc. The final products of this is Graphite powder, Cobalt acid lithium Aluminum and Copper.

3-22. Figure_ Raw Materials

3-23. Figure_ Final Product



3-24. Figure_ Flow chart
[https://www.sunymachine.com/NEWS/Processing-Technology-of-Waste-Lithium-Batteries.html]

Advantages of the recycling process:

1.High automation program, simple operation, stable performance;

2. Low power consumption, low noise, small footprint, no dust pollution;

3.Electrical separation efficiency of 99%, finished products can be sold directly;

4. Wide range of sorting materials, fast sorting speed;

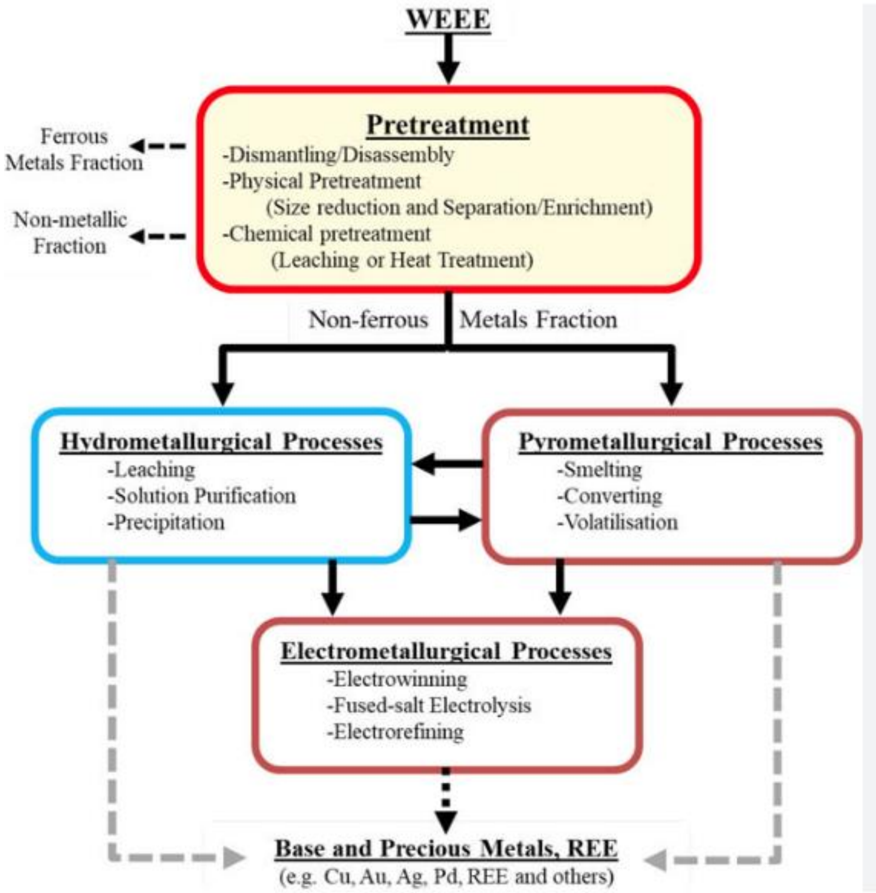
4.No waste gas emissions, real sorting for green environmental protection, no generation of secondary pollution;

5.Lithium battery recycling equipment adopts water-cooled and air-cooled turbine mill, which makes the material separation cleaner and more suitable for their recycling.

4 WEEE – TECHNOLOGIES AND TRATMENTS

The degradation of WEEE waste takes place over thousands of years, it can also contain toxic substances, and the faulty management of this waste poses major risks to both health and the environment. Recycling WEEE is not simple and easy, it contains hazardous substances as well as iron, aluminum and copper, and when properly recycled, these valuable metals are reused as secondary raw materials and pollutants are removed in a controlled manner.

In a first mechanical step, different components and devices can be separated into various fractions such as: metals (iron, copper, aluminum, etc.), plastics, ceramics, paper, wood and devices such as capacitors, batteries, picture tubes, LCD -s, printed circuit boards, etc. Later these fractions can be treated separately until complete recycling is achieved. To be able to be used, these fractions are further processed through other treatment methods, being enriched with certain materials, through processes such as pyrometallurgy or hydrometallurgy.



4-1. Figure_ Unit processes in the treatment of WEEE for recovery of the contained values [https://www.researchgate.net/publication/330468620_Recent_advances_on_hydrometallurgical_recovery_of_critical_and_precious_elements_from_end_of_life_electronic_wastes]

Due to the high halogen content, the plastic materials are chemically removed, and the metal fractions will be treated by various metallurgical processes. Separation of components from printed circuit boards can cause great problems because the metallic and non-metallic fractions are highly cross-linked.

After removal of contaminants and manual sorting of mercury switches, capacitors containing PCB and other parts, the resulting material will undergo a crushing process to reduce size. When separating the material, various methods can be used, namely: magnetic, electrostatic, density, visual, etc.

Ferrous metals in conveyors can be sorted and removed using large magnets. Energy consumption can be significantly reduced if permanent magnets are used instead of traditional electromagnets. In order to increase the recovery percentage of ferrous metals, the reprocessing operation is necessary, i.e. making multiple passes through shredders and magnets. After removing the ferrous metals, large pieces of materials such as glass or plastic are removed.

Further crushing or hammer grinding processes connected by conveyors can be used to achieve very small sizes. The range of devices used depends largely on the composition of the waste. [34]

4.1 Separation technologies

Separation of materials is important to ensure a high quality product ready for use in new products. Various material separation equipment uses airflow or water with oscillating movements or magnets or currents to separate the materials according to their specific properties. Material separation equipment depends on the type of waste or scrap and the fractions we want to separate.

All metals that do not contain iron or alloys derived from iron in their composition are classified as non-ferrous metals. [35] Depending on the density, they can be classified into:

- *Ultralight metals*: density less than 2,000 Kg/m3 → Magnesium;
- *Light metals*: density greater than 2,000, but less than 5,000 Kg/m3 → Aluminum, Titanium;
- *Heavy metals*: density greater than 5,000 Kg/m3 → Copper, Lead, Nickel, Tin, Chromium, Zinc.

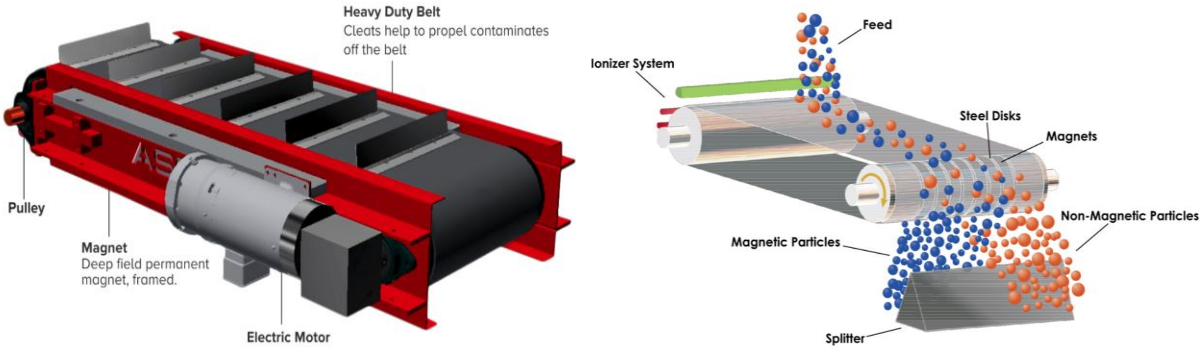
The non-infinite mineral reserves, the high cost of extraction and processing, the economic value that the metal (Fe / Non-Fe) retains despite being classified as waste, have encouraged separate collection and recovery for reuse.

One of the most effective and widespread methods of recovery and separation of non-ferrous metals is separation by physical principle, i.e. by means of induced currents (or eddy currents).

Non-ferrous metal impurities, which have reached the area of influence of the magnetic field (rotated at high speed / frequency), undergo a rejection that separates it from the flow of material to be processed. These machines are usually accompanied by magnetic separators with mechanical removal to also recover the stainless fraction, which is completely inert to Eddy Current machines.

1. Magnetic separators

It is a method used to separate ferrous and non-ferrous components from waste. A conveyor belt equipped with NdFeB magnets is fed with waste, when the waste reaches the end of the belt, it passes over the magnetic roller, where the non-magnetic particles are discharged into a hopper. The magnetically sensitive particles are attracted by the magnetic roller under the conveyor belt so they pass around the roller and fall into the second hopper.



4-2. Figura_ Magnetic separation scheme [https://discountsales.onlinesales2023.com/]

2. Eddy Currents Separators

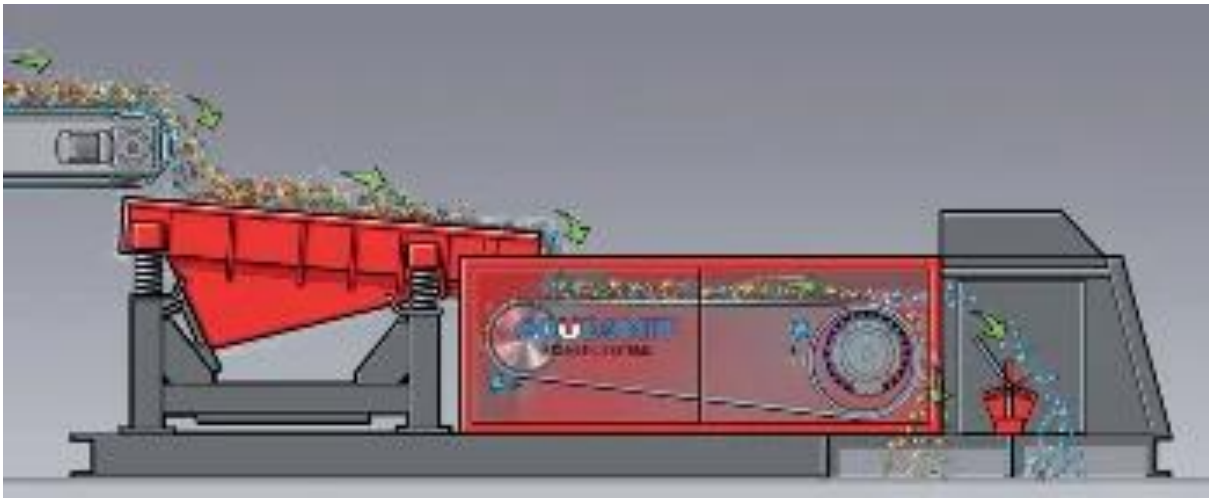
It is a similar concept to magnetic separation, a rotor is aligned with neodymium magnets with alternating north and south poles. The rotor produces an external magnetic field, which repels electrically conductive non-magnetic metals, thereby expelling them from the waste stream, leaving the non-metallic particles behind. The magnetic field can be controlled by the speed of the rotor. Materials with different conductivities produce different eddy currents and will therefore be thrown at different distances. [36]

Thus we can state that the non-ferrous metals will be evacuated from the inert flow with the force proportional to the ratio between the electrical conductivity and the specific gravity. The greater this ratio, the greater the force exerted and, consequently, the greater the repulsion.

The easiest non-ferrous metals to separate are: aluminum (Al): ratio 13.1, magnesium (Mg): ratio 13, copper (Cu): ratio 6.6, silver (Ag): ratio 6.5.

The most difficult non-ferrous metals to separate are: Zinc (Zn): ratio 2.5, Tin (Sn): ratio 1.2, Lead (Pb): ratio 0.45.

The rotational speed of the eddy current separator rotor determines the frequency of the induced currents and, consequently, the repulsion force.

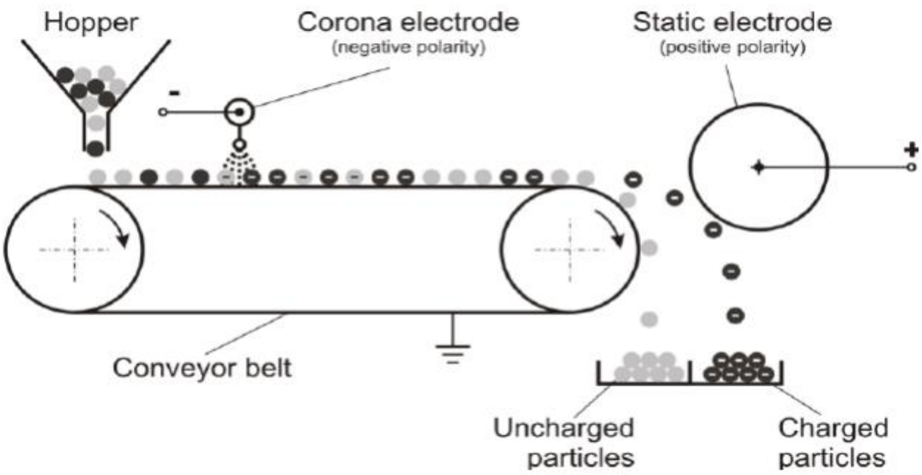


4-3. Figure_ Induction separators(Edy Curent)[https://www.azom.com/]

3. Electrostatic separators

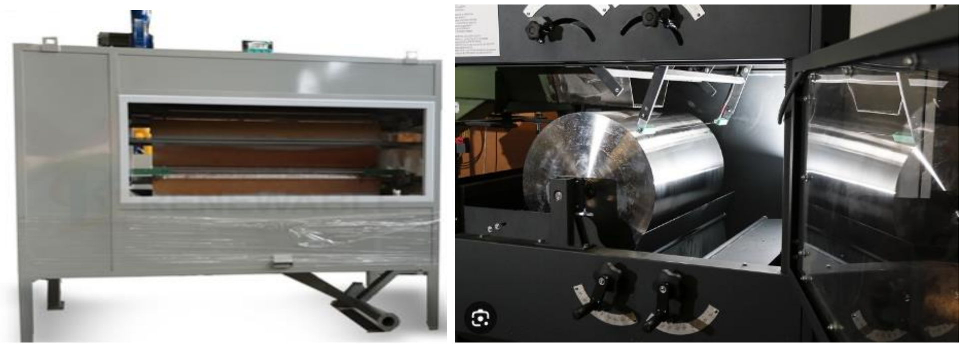
Electrostatic corona field separation is a widely used separation technology in industry because it is an efficient and environmentally friendly means of recovering metallic and non-metallic parts from the waste stream. Electrostatic separation, defined as "selective sorting of charged or polarized bodies in an electric field", presents an efficient way to recycle metals and non-metals from WEEE without or with minimal negative impact on the environment.

Electrostatic corona separation is a process in which metallic and non-metallic particles are electrostatically charged when they enter a field and are "ion bombarded" by the corona charge. The metallic particles are quickly discharged at the ground electrode while the charged non-metals on the other hand are "shot" by the electric force of the rotating roller and rotated until they are finally released into the collecting tanks. The separation is achieved due to the different electric field forces acting on the metallic and non-metallic particles. [37]



4-4. Figure_ Electrostatic corona separation [Reproduced from Dascalescu et al, 2010]

Electrostatic separator is used to separate metal and non-metal. It adopts the principle of high-voltage electrostatic processing, separating metallic and non-metallic materials according to different conductivity. This machine can be used for all kinds of separation of metal, plastic and other non-metal materials, such as waste printed circuit boards, cables, aluminum, plastic and other waste materials. [38]



4-5. Figure_ Electrostatic separator [www.reyclinginside.com]

Product features:

1.High precision separation.

2.Easy to operate,simple to maintain.

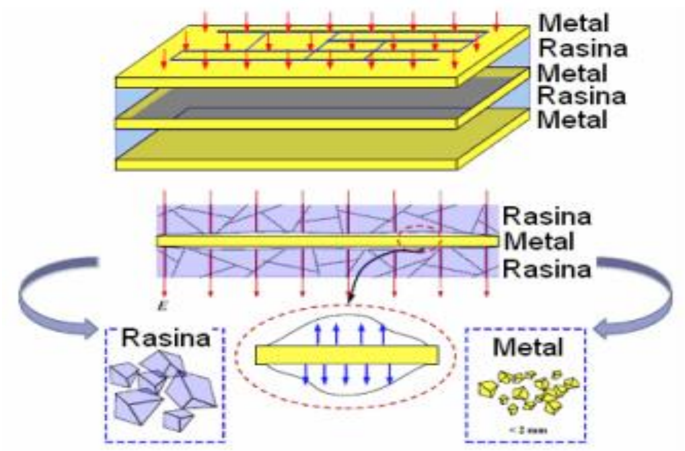
3.Cover small area and it easy to move.

4. Selective electrodynamic fragmentation

One process for separating composite structures that include metals is selective electrodynamic fragmentation. This process is used for the recovery of waste from decommissioned bridges.

The energy developed by the pulsating, high-voltage electrical discharges that are produced in the composite structures is used to separate the components. The block diagram of the installation (figure below) includes the high power and high voltage source to ensure the charging of the capacitors, the repetitive pulse generator and the processing container in which the dielectric medium (water, oil, etc.) is located, respectively the material to be processed.

The process is based on the ability of ultrashort (< 500 nsec) underwater pulses to selectively break up solid materials into fragments. This works because the spark discharged has a marked tendency to travel along the phase boundaries in the solid material. Electrical breakdown generates a pressure wave (p = 10 GPa), which breaks down the composite material into its component parts. This technology is already being used for special applications.[39] [*FRAUNHOFER INSTITUTE FOR BUILDING PHYSICS IBP]*



4-6. Figure_ The principle of selective fragmentation [http://www.icpe-ca.ro/icpe-ca/proiecte/proiecte-nationale/pn-2014/itesedez.pdf]

During the process of shredding WEEE waste, PCB electronic boards by pulses that are applied through a working electrode to form an electric field.

The destruction of solid materials by electrical discharges in pulses called - electrodynamic fragmentation, assumes that under the action of the applied electric field, the Cu sheet produces sufficient polarization charges, resulting in an increase in the number of positive and negative electrical charges that accumulate on the two sides of the sheet by Cu.

The same phenomenon of polarization under the action of the electric field is also achieved in epoxy resin and cane fibers. By distorting the electric field at the interface of different materials, the intensity of the electric field increases and separation occurs.

4.2 ASR recycling technologies

Auto Shredder Residue or ASR recycling technology, manages all light fractions left over from end-of-life vehicle (ELV) recycling. This material also known as Shredder Light Fraction (SLF) from machine fractions represents up to 25% of the ELV weight and contains different materials: plastic, rubber, glass, sand, textiles, wood, metals and dust.

ASR recycling is the process of reducing material to sort materials for recycling and/or to produce a fraction suitable as an alternative fuel. The most sought after materials are various metals and plastics. As many countries do not allow metals and harmful fractions such as PVC to be incinerated or landfilled, ASR recycling is an important part of car recycling.

ASR recovery is becoming increasingly important around the globe, as nearly three million tonnes of ASR are generated per year. European Directive 2000/53/EC established the requirement that vehicle and equipment manufacturers must ensure that new vehicles are reusable and/or recoverable to a minimum of 95% of the weight per vehicle. To achieve these goals, various chopping and shredding technologies have been developed with the aim of improving material and energy recovery from ASR.

Among the available ASR solutions for the recovery of automotive residual electrical cables such as communication cables, power cables and electronic cables, shredding technologies are known where the disassembled bodies pass to powerful crushing and shredding machines that reduce them to small fragments. The shredded material can then be processed to separate different types of metallic and non-metallic substances such as plastic and Cu. Most of this material can be reused in a wide range of industrial applications. This process allows copper or aluminum to be reused, reducing the need for new mining and production of these metals and reducing the amount of waste that ends up in landfills.

Commonly used equipment for recycling waste cables include scrap cable shredders, industrial cutting machines, copper cable granulators, etc.

The following shredders are known as powerful crushing and shredding machines that reduce them to small fragments:

1. Primary shredders

Primary shredders are used to reduce the initial size or pre-shred the input material to prepare it for further processing. The primary shredder can also be used to increase the capacity of a recycling facility or to make bulky waste denser for easier transport.

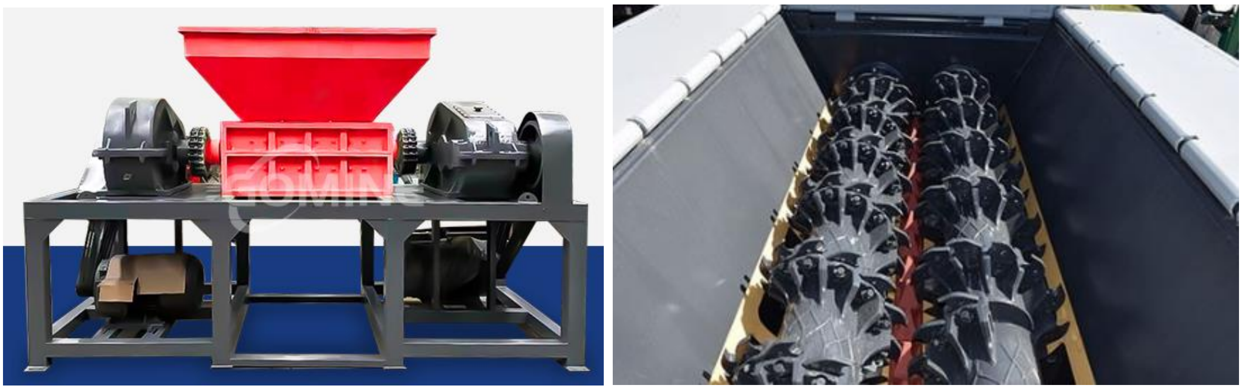
Secondary shredders are used to reduce the secondary size of different materials to ensure the release of different fractions and prepare them for sorting. Some secondary shredders can also be used as primary shredders for low capacity installations or for relatively small input materials.

4-7. Figure_ Post shredding technologies[https://www.altramotion.com/]

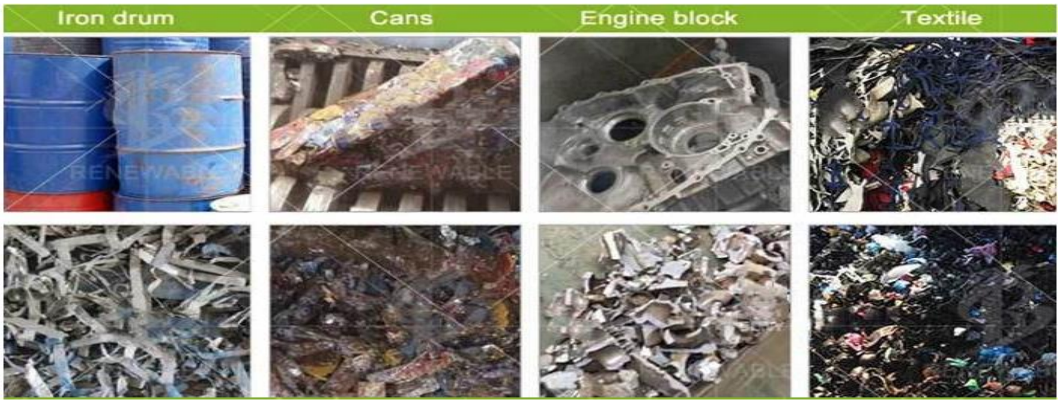
The shredding pilot program achieved a recycling rate of 91.2% for materials and a recovery rate of 96.9%, including energy recovery. These results show that the total target of 95% can be and has been achieved. This was possible due to the recycling designed for the Prius Plug-in car from Toyota and the quality of the technologies and equipment used.

2. Two axis chopper

The double spindle shredder is a pre-processing equipment for the material to be chopped, pre-sorted and fed into the two shafts whose rotors move slowly in opposite directions being a dust-free and noise-free processing because the cutting discs are stuck on the shaft. This dual spindle shredder is designed for longevity. The number of knives, respectively their width, determines the size of the output material.



4-8. Figure_ Two axis chopper [https://www.gominerecycling.com]



4-9. Figure_ Raw material and finished product[40]

Advantages of the double spindle shredder:

1. The chopping blades are made of special materials: 9CrSi, Cr12MoV, SKD-II, D2, DC53, etc.

2. The crushing chamber is very thick made of steel plate, very strong and durable, thus prolonging the service life of the equipment.

3. Shredder blades can be designed with different thicknesses for processing different raw materials.

4.3 Cu separation technologies

World production of copper is over 15 billion kilograms. Copper is a 100% recyclable metal being the third most recycled metal after iron and aluminum. About 80% of all copper mined is still in use today and about 33% of the Cu used today is supplied from recycled materials, so recycling remains a key element in meeting the copper requirement in the industrial market.

Generally, about 65% of the copper produced is used for electrical applications (power generation, transformers, motors, cables, electrical circuits, wiring and contacts for electronic devices). 25% of all copper produced is used in buildings (for plumbing, roofing and cladding. Transport accounts for 7% of copper use (trains, trams, cars), of which a major part is used for electronic purposes. The remaining 3% is used for coins, sculptures, musical instruments and cookware. [https://ro.wikipedia.org/wiki/Cupru]

The copper recycling process follows roughly the same steps as copper mining, but requires fewer steps. The obtained high-purity copper waste is melted in a furnace and then cast into ingots; those of lower quality - the remnants of poor purity, are refined by electroplating in a sulfuric acid bath. Copper alloys are usually recycled by careful analysis of its composition after which pure copper can be added to produce new alloys.

The main purpose of cable recycling is the reuse of copper to reduce the extraction of new natural resources and to promote the circular economy. Proper disposal of used cables allows a perfect separation of the insulating material (PVC and/or rubber) from the metal with close to 100% purity. [41]

Granulators are used to reduce the secondary or final size of granulation to release different materials and prepare them for sorting.

Electrical cables, industrial and automotive wiring are an important resource for the recovery of conductive metals from them, especially copper and aluminum, such as:

- teak cables of any size
- extremely thin cables (telephone cables, data cables, cables from computer recycling), cables from electrical and electronic equipment (RAEE-WEEE), capillary cables

cables from the demolition of vehicles polluted with sticky and oily materials.

4-10. Figure_ Cable recycling facility - STOKKERMILL TURBOFLEX LINE

The feed conveyor is used to feed the copper wire and cables into the machine, while the copper shredder shreds the wires and cables into small pieces. The conveyor belt then moves the shredded material to the separation system, which separates the copper from the plastic insulation.

The capacity of the copper wire granulating machine is usually 100 kg per hour, and the power source can be single-phase or three-phase, which is more suitable for small recycling enterprises and services.

Machines and granulators for recycling copper and aluminum cables from the automotive industry are equipped with turbo units capable of handling mixed and extremely thin diameter cables. Zigzag separators allow recovery of the heaviest fraction of copper from larger diameter cables. Due to the large working surface of the densitometric separation tables, it is possible to obtain Cu granules with high quality purity, close to 100%.

The copper cable recycling and aluminum granulation plants work by granulating and separating the copper from the insulating part or the aluminum copper. These systems are created to optimize the quality of the output product. In the first phase of the treatment, the dimensions of the material are reduced using the pre-shredder, followed by the removal of all metallic impurities using a magnetic separator. The processing and recycling of the cables continues through the Turboflex granulator which allows shredding the electrical cables and separates the metal part (Cu and Al) from the plastic. The final step is then sifting and sorting with a vibrating screen.

4.4 PCB's separation technologies

A complex component of WEEE is the waste from printed circuit boards where the presence of toxic metals and precious metals makes the recycling of this product necessary in order to combat environmental degradation, but also to capitalize on economic opportunities. The high cost of printed circuit boards (PCBs) in the automotive industry shows the need for end-of-life recycling.

Due to the high value of rare metals, fiber and resin contained in the tiles, there is no doubt that recycling not only helps turn waste into treasures, but also brings great economic benefits. Through years of practice and theoretical analysis, the best separation result can be achieved by achieving a purity of up to 99%.

From the perspective of WEEE, information on the material characterization of PCBs embedded on them is widely available in the literature.

In the automotive sector, the recovery of platinum group elements is essential and useful both for CE (European Community) objectives and for mitigating the demand for these materials. It is known that Platinum (Pt), Palladium (Pd) and Rhodium (Rh) are very present in automotive catalytic converters and their demand in the market is constantly increasing. Thus, digitization can support the recycling of metals, and attention to the development of EC models should also be directed to non-metallic components.

We can say how important it is to ensure waste collection infrastructure that could also ensure a sustainable market for secondary raw materials. Prompt and effective measures in this regard would have a direct impact on the management of waste, including e-waste and end-of-life vehicles, their repair and reuse, the recovery and recycling of the resources contained therein, as well as the reduction of their environmental impact and impact on human health.

Furthermore, considering the current evolution of transportation towards hybrid and electric technologies with self-driving systems, growth is expected in the coming decades.

Therefore, it is of utmost importance that we solve this problem before it becomes unmanageable. Only by highlighting the problem and trying to quantify it can we hope to enable a positive discussion among experts and a change in the mental models of decision makers in international governments and industrial companies.

In general, a technological process can be seen as the sum of six main phases that, starting from PCB (main board) waste, allow to obtain a set of (almost pure) raw materials as a final result. These phases can be distinguished in:

- collection,
- pretreatment,
- disassembly,
- shredding,
- separation and
- refining.

Initially, PCBs (main board) are ***collected*** from different actors (e.g. used PCB traders, treatment facilities, dismantlers, etc.). After an initial pretreatment (where PCB waste is cleaned by operators), the subsequent disassembly phase allows the removal of toxic components present on the main board (eg capacitors or batteries) by distributing them to specific treatment stations.

PCB dismantling facility *(main board)*

The automated electronic component dismantling plant is used to remove electrical components from PCB (main board) waste that contain various precious metals that can be sold separately or directly at a better price. After removing the components the base plates are crushed and ground to easily separate the copper. This facility means that precious metals can be recovered in larger quantities reducing the work for the next step of recovery.

4-11. Figure_ Recycling technology of WEEE [https://copper-recycle.com/recycling-machines/PCB-dismantling-machine.html]

Product advantages

1.Full automatic working.

2.Tin remove and dismantling components at one step.

3.Automatic temperature controlled by our heating system.

4.Large capacity:200kg/h, 300kg/h, 500kg/h.

5.Operating safety and easily.

6.Less damage to the components, keep the precious metals no losing.

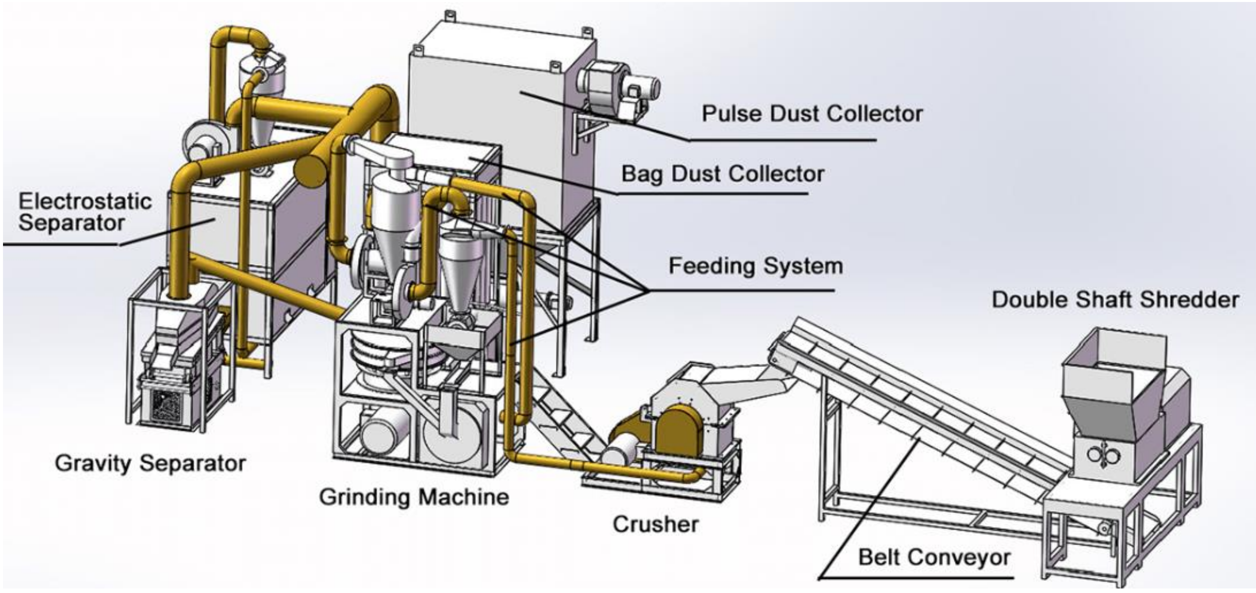
PCB shredding plant *(main board)*

4-12. Figure_ E waste PCB circuit board recycling machine [https://www.sunyrecycle.com/circuit-board-recycling-plant]

4-13. Figure_ Applications / Final product

During the comminution phase, the waste PCBs are crushed into micro pieces to a uniform powder by several machines (eg choppers, grinders, hammer mills, etc.). When the correct granularity is achieved, the powder is separated based on its composition (technologies do this by exploiting the physical and chemical characteristics of the powder), separating metal from non-metallic powders. Nowadays, the latter are destined for landfills, but there is interesting work investigating alternative (and valuable) ways to reuse them for different purposes.

For example, the E waste PCB circuit board recycling machine consists of shredding system, milling system, sorting system and dust collection system. The whole process is controlled by PLC. Through shredding, grinding, vibration screening, (the incompletely separated metal and nonmetal will reentry into the grinding machine to be grinded again) gravity separating, electrostatic separating and pulse dust collecting, the metal and nonmetal will reach about 99% of separation, eventually get metal and non-metallic collective, and the valuable components after dismantling machine can also be recycled refined.



4-14. Figure_ PCB shredding machine E [from SUNY GROUP]

Process description

The first crushing machine is the double shaft shredder, and the second crushing machine is the hammer crusher, and the third crushing machine is the high-speed turbine grinding machine. Thus, the material after shredding, crushing and grinding will be separated by air separator and electrostatic separator. It has the advantages of unique structure is to achieve high output and save energy. The whole station works after one material loading and is PLC programmed. This machine has good performance in copper recycling and comes with a secondary pollution prevention device. The metal recycling rate is up to 99%.

4-15. Figure_ Technological line [from SUNY GROUP]

Finally, metal powders are refined by various technologies (eg, pyrolysis, pyrometallurgy, hydrometallurgy, biometallurgy) until almost pure secondary resources are obtained. However, before any type of PCB waste is treated, a materials characterization phase always takes place. This means a definition of the set of materials embedded in a certain quantity of PCBs, through the chemical analysis of a sample of them. This phase allows:

(i) understand the presence (or not) of valuable materials and

(ii) to define the expected revenues from their recovery.

Electrical waste treatment machines (WEE) are able to treat different parts from which electronic materials are made in order to recover fractions of ferrous and non-ferrous metals allowing obtaining homogeneous materials of high quality purity. The production capacity of WEEE recycling lines varies depending on the type of materials to be treated, which are generally:

- Electronic and telecommunications equipment (equipment for transmitting sound, images or other information)
- Consumer equipment (musical instruments, speakers, video devices, video cameras...)
- Lighting equipment (interior, exterior)
- Monitoring and control sensors, etc.

4.5 Pyrometallurgical treatment

Processes that include, melting in a plasma arc furnace or blast furnace, incineration, sintering, melting and gas phase reactions at high temperatures are called pyrometallurgical processes.

Thus, incineration is a common way to get rid of plastic and other organic substances to recycle metals.[42] The crushed residue can be burned in a furnace or molten bath to remove the plastics, leaving a molten metal residue. The plastic burns and the refractory oxides form a slag phase. [43]

Collector metals such as copper or lead can be used in smelting reactions. In order to obtain raw metal, a process must be used to obtain the melting of impure alloys. The recovery of silver and gold as waste materials can be carried out in a copper smelter for a long time.

Pyrometallurgical processing is the most widely used method for the recovery of secondary copper and a large part of electronic waste through copper smelting, a process that involves the reduction and melting of the material, the production of blister or raw copper in the converter, fire finishing, electrolytic refining and anodic mol processing.[44] However, the method used for copper extraction depends on the nature of the ore.

It is known that the hardness of copper is relatively low (3 on the Mohs scale), but it is quite resistant to breaking, and very ductile (it can be drawn into wires), being able to be shaped at high pressures. The thermal conductivity is similar to that of silver (1 to 0.93 of silver) and much higher than other common metals. Precisely because of this property, copper is used in pipes to transmit heat. However, the conductivity decreases when the copper is impure. When it contains 0.1% impurities of elements such as phosphorus, arsenic, silicon or iron, the conductivity value can decrease even by 20%. That is why only pure, electrolytic copper is used in electrotechnics.

The percentage of recycled copper in Europe increased to 41.3% in 2007 and to 43% in 2008. The production of secondary refined electrolytic copper increased from 800 to 857 thousand tons, while the use of direct smelted copper decreased from 1,242 to 1,150 thousand tons. The use of scrap copper decreased from 2,042 thousand tons in 2007 to 2,007 thousand tons in 2008, but despite the decrease, due to the estimated decrease in the manufacture of semi-finished products, the ratio of recycled copper to production increased. A good property of copper is its infinite purity during recycling. Copper recycling can be done from old faucets, old pipes, etc., as well as from waste produced by direct melting of circuit boards.

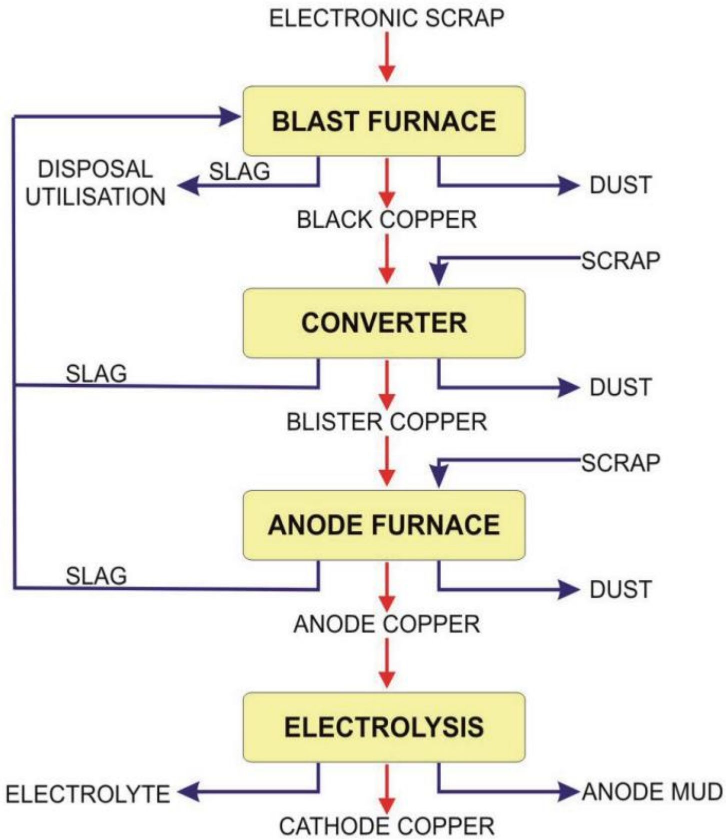
The pyrometallurgical process aims to obtain a mass of copper with a concentration of 40...60% Cu in the form of Cu_2S through a process of melting the concentrates in the presence of short (SiO_2) as a base. This operation is aimed at the partial removal of iron by zurification in an oxidizing medium in the presence of curd and the concentration of copper in an intermediate product called matte. Mata is a complex solution of sulfides in which the main components are Cu_2S and FeS.

The main technological phases are:

- partial roasting of the concentrates,
- melting for the mat,

- conversion of mats,
- thermal refining and
- electrolytic refining.

The figure below illustrates a typical waste recycling process for electrical and electronic equipment containing copper.



4-16. Figure_ Recycling process of WEEE containing copper
[[PDF] Recovery of Metals from Electronic Waste by Physical and Chemical Recycling Processes]

In a modern copper smelter, several types of copper-containing materials are recycled. In addition to copper, WEEE materials contain nickel, lead, tin, zinc, iron, arsenic, antimony and precious metals, among many others.

4.6 Hydrometallurgical treatment

Hydrometallurgy is part of a multitude of processes carried out in liquid form, for the recovery of metals from ores, concentrates and salt solutions. The extraction of zinc, nickel and lead is done by solubilization in a multi-step process.

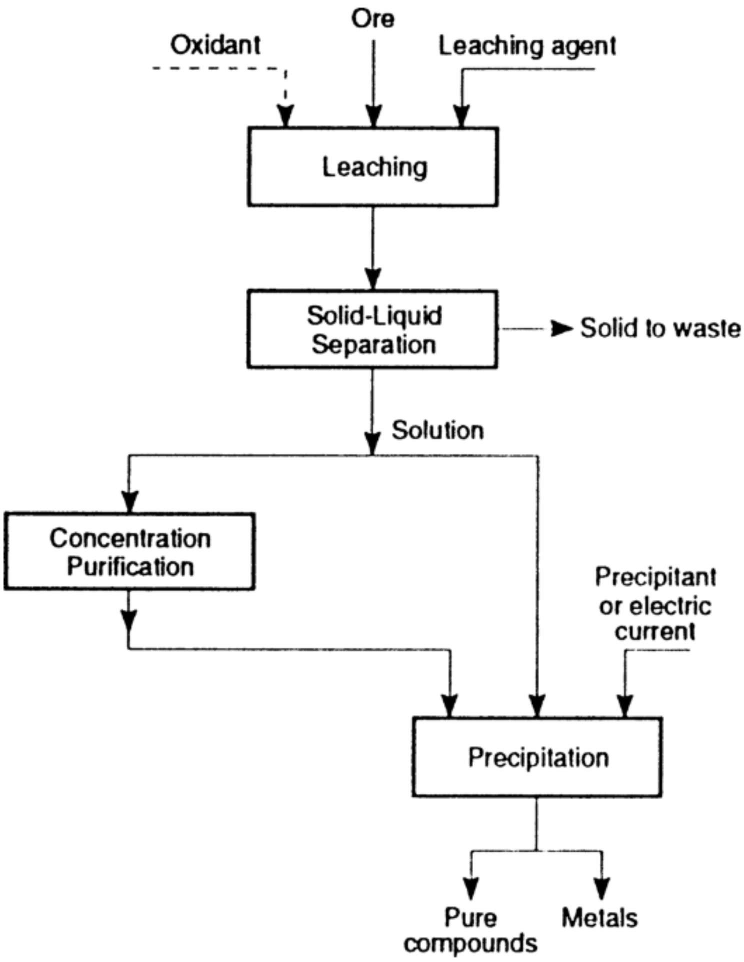
Hydrometallurgy through the direct solubilization process recovers gold from the PCB recycling process. Most hydrometallurgical processes are carried out in several complex stages, at each stage specialized chemicals are required, either to recover the metal with impurities to refine it by removing its impurities to obtain a nearly pure product. Most hydrometallurgical processes include an alkalization step. These processes are much more efficient if the correct choice of chemicals and their purity is ensured.

The solution most used in hydrometallurgical treatment is lime, being the alkaline chemical substance (milk of lime), used in the recovery of hydrometallurgical metals, such as: gold extraction, removal of nickel, lead and zinc impurities.

The hydrometallurgical process currently provides approximately 25% of the world's copper production obtained from the recycling of WEEE and is mainly applied to oxide ores and less to sulfur ones.

The main technological phases are:

- preparation of raw materials (crushing /grinding)
- solubilization
- purification of solutions or their concentration by extraction with organic solvents
- copper extraction through cementing solutions, electrolytic extraction or solution reduction.



4-17. Figure_ The recycling process through the hydrometallurgical process [https://www.researchgate.net/publication/261569818_Mechanochemistry_in_Technology_From_Minerals_to_Nanomaterials_and_Drugs]

Most industrial processes use sulfuric acid solutions and less often ammonia solutions as solubilizing reagents. Using this process requires small grain sizes to increase metal yield. Leaching solvents are mainly H2SO4 and H2O2, HNO3, NaOH, HCl, etc.

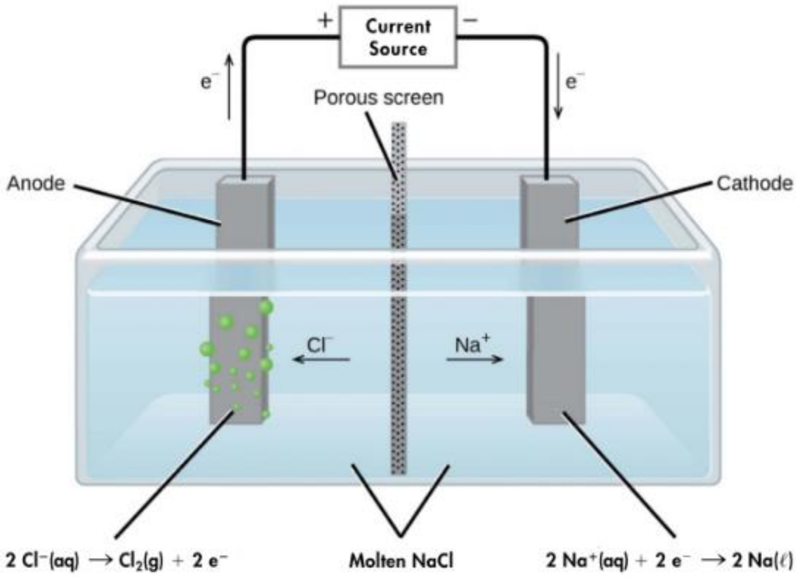
4.7 Electrometallurgy treatment

Electrometallurgical treatment is used to reduce metal ores or refine metals and is based on electrolysis, which involves the electrolysis of a molten salt or an aqueous solution. Electrolytic methods are important for obtaining more active metals such as sodium, magnesium and aluminum. These metals cannot be obtained from aqueous solution because water is more easily reduced than metal ions. The standard reduction potentials of water under acidic and basic conditions are more positive than those of Na+, Mg2+ and Al3+.

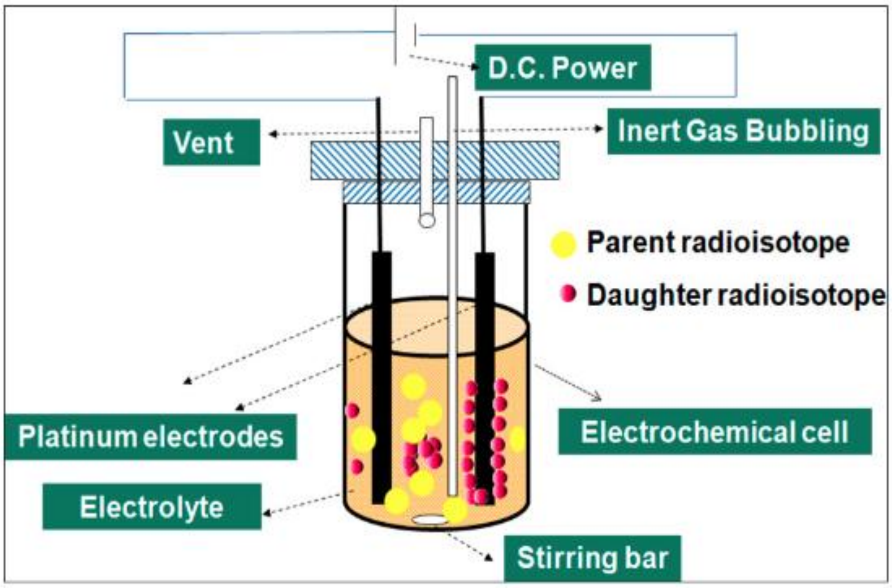
Most electrochemical treatment methods are usually refining steps and are carried out using aqueous electrolytes or molten salts. Only a few processes can be found in the literature that could look for shredding directly in electrolysis.

Therefore, electrolysis is very important as a step in the separation of waste elements using an electrolytic cell. The electrolytic process requires an electrolyte, an ionized solution, or a molten metal salt to complete an electrical circuit between two electrodes. When the electrodes are connected to a direct current source, one called the cathode becomes negatively charged (-), while the other, called the anode, becomes positively charged (+). The positive ions in the electrolyte will move towards the cathode and the negatively charged ions towards the anode.

As an example of treatment we can give iodide electrolysis where an aqueous solution of KI/KOH is used to recover gold, silver and palladium from plated or coated scrap metal.



4-18. Figure_ Electrolysis cell schematic [https://chem.libretexts.org/]



4-19. Figure_ Electrochemical separation [https://pubs.acs.org/doi/10.1021/ie404369y]

Another process is the Fe process, in which copper-based scrap is leached into a sulfuric acid solution in the presence of trivalent iron. The leach solution is electrolytically regenerated. [45]

Copper obtained by pyrometallurgical processes, after thermal refining, still contains a series of impurities that substantially affect its physical properties: electrical and thermal conductivity, plasticity, etc. The advanced purification of copper, up to concentrations of over 99.9%Cu and impurities of a maximum of 0.005%, is carried out electrochemically through the electrolytic refining process, which pursues two main purposes:

- removal of impurities

- recovery of some elements especially the noble metals Ausi Ag and some rare metals.

Electrolytic refining is based on an electrolysis process with soluble thermally refined copper anodes, electrolytic copper cathodes, and as an electrolyte an aqueous solution of sulfuric acid and copper sulfate. [46]

The advantages of electrolysis over chemical methods for obtaining various metals from waste lie in the control of the rate and selectivity of the reaction by easily adjusting the current. Thus, the conditions for electrolysis are easily controlled.

5 WEEE & ELV's MANAGEMENT

Waste management in the automotive industry involves the recycling and reintroduction of some waste (metal, oils, solvents, batteries, plastic and glass). Recycling these materials helps economic operators to address environmental concerns and solve the problem of resource depletion.

In order to obtain quality management, each company, OEM or workplace must present a Waste Management Plan that will include a Waste Generation Prevention Program in accordance with GEO 92/2021 art.44(1) for the purpose of prevention and reduction the waste generated by them.

The waste management policy must refer to the prevention and continuous reduction of the environmental footprint through the proper management of waste generated by:

a) awareness
b) implementation of internal rules
c) orientation towards prevention, recycling and recovery
d) allocation of financial resources for waste treatment
e) applying an environmental management system according to ISO 14001:2015 in order to continuously improve environmental performance.

Thus by applying an ISO 14001 certified Environmental Management System in order to ensure continuous environmental performance regarding the prevention and reduction of the environmental footprint and its impact through:

- Optimization of energy consumption and atmospheric emissions;
- Appropriate use of raw materials;
- Reduction at the source and maximization of the value of waste obtained from dismemberment;
- Prevention of soil and groundwater contamination;
- Controlling water consumption and aqueous discharges into the aquatic environment;
- Prevention of accidental pollution and reduction of sound and olfactory nuisances;
- Keeping the chemical risk under control;
- Implementation of optimal waste transport solutions, etc.

Thus, the designated person will be responsible for the separate collection of waste in containers and in specially designated spaces, with the aim of preventing the mixing of hazardous waste with non-hazardous waste and at the same time with the aim of preventing the generation of an additional amount of waste and avoiding pollution of the environment, according to the provisions of GEO 92/2021.

5.1 Automotive sector analysis

With a share of 14% in Romania's GDP, the Automotive Industry has become the country's most important industry, contributing to the country's exports with over 26% of sales. Due to the relatively cheaper labor force compared to other EU countries, the high quality of human capital or the competitive tax system, several foreign investors have chosen Romania for the development of this industry. The modular design of components for disassembly contributes significantly to the potential for circularity in the automotive sector which refers to reducing energy consumption and increasing product durability, as well as increasing the reuse and recycling of products and materials.

Currently, over 45% of the cars owned by Romanians (about a third) are older than 16 years, it follows that in the near future Romania will end up facing a considerable amount of complex waste represented by end-of-life vehicles, for which no currently has an adequate, modern and automated recycling infrastructure. Moreover, currently the steel and aluminum industries, insufficiently technological, do not have the capacity to absorb the recyclable material resulting from the mechanical parts resulting from the scrapping of old cars.

Considering the number of second-hand cars arriving in Romania, it would be justified for the steel industry in the country to equip itself with the latest technologies in order to capitalize on the resulting waste and increase its competitiveness. This could be achieved, for example, by switching from the conventional blast furnace process to more energy-efficient and less CO2-consuming processes, such as the HIsarna process, which incorporates scrap metal into the process. Other examples are that of Nippon Steel Corporation's Hirohata Steel Plant, which uses technologies that recycle tires in steel production, or that of the electric arc furnace technology, which relies heavily on waste.

Specific to Romania, the faulty communication between dismantling companies, manufacturers, waste disposal companies and authorities affects the flow of recovery of waste from the automotive industry. As a result, dismantling companies mainly focus on reselling parts for their value, and therefore focus heavily on only those parts that can be resold as such. This leads to little attention to those parts that can be reused with minor repairs or recycled. Thus, parts with low demand or low resale value end up in the landfill. In addition, due to the low volume of recycled material, the price of recycled materials is higher than the price of some raw materials, which further discourages recycling. Moreover, illegal dismantling of end-of-life vehicles contributes to tax fraud, pollution and degradation of human health and biodiversity, particularly through fire-based metal separation procedures.

Another challenge for the recycling of end-of-life vehicles in Romania is the lax legislation on the abandonment of old cars, which causes many cars to be abandoned on city streets and in landfills. Abandoned vehicles lead to poorer scrap quality, leakage of hazardous substances into the environment and a more expensive scrapping process due to the bureaucratic steps that need to be followed.

In addition, Romania still lacks modern infrastructure, such as robust and high-quality national highways and roads. This has a clear and direct effect on the state of the car fleet in Romania, ultimately reducing the lifespan of every vehicle that frequently uses this infrastructure.

The trend of electrification of the automotive sector is also manifested in Romania. This perspective opens up new challenges for the circularity of the industry, battery production and their reuse and recycling becoming a whole new issue at EU and global level. Electric vehicle batteries can be reused and reused under the conditions that will result from the transposition of the new EC legislative proposals. Reuse applications include storing energy from renewable sources as a form of backup power to reduce power outages during periods of instability or shortage of renewable sources (eg less sunny days). This application can be used both on a large scale by energy suppliers and on a small and medium scale by energy communities or individual consumers who produce the energy they consume themselves - the so-called prosumers. However, at present only a small fraction of end-of-life batteries can maintain a reasonable storage capacity after the first life cycle to justify such reuse. Regarding battery recycling, the current technology is not economically, environmentally and logistically viable.

Therefore, research and innovation are currently needed to produce, on the one hand, batteries with a longer lifetime and high storage capacity after the first life cycle, and on the other hand to develops economically and ecologically viable technologies for dismantling batteries in order to recycle their components. As mentioned, this is not a problem specific to Romania, but rather a global one. However, Romania should be ready to adopt and apply these technologies when they become available.

5.2 Automotive solutions and opportunities

At the design stage, for repair, reuse and recycling, the vehicle design should allow for disassembly. A modular construction of components, where individual spare parts can be repaired or replaced without affecting other well-functioning components that can and should be kept as such, is a way to ensure repair, remanufacturing and optimal use of the materials.

As the automotive industry in Romania is mainly owned by foreign investors and many design decisions are made at the headquarters of the main investor, this is not generally true. For example, the Renault Group has one of six design offices in Bucharest, where, at the beginning of this year, 30 designers were employed. This office has designed important parts for Dacia and is in constant internal competition for projects within the Renault Group.

Therefore, there is potential for Romania to influence the design choices of the country's major automakers along the lines described above. For these design goals to be achieved and for the influence to be extended, the automotive research and development sector in Romania must be consolidated and well funded, including at the level of university and professional education.

In the production phase, the key elements are the reduction of energy consumption and waste (resulting from overproduction, defects, unnecessary stock, improper processing, excessive transport, waiting times, unnecessary movements or poor workplace organization), improving the durability of products through increasing manufacturing quality, using recycled parts and raw materials, improving remanufacturing.

In the use and reuse phase, while electric vehicles partially solve the problem of lifetime energy consumption, some common circularity issues remain between these types of vehicles and combustion engine vehicles. In fact, the decarbonisation of the automotive industry goes beyond battery vehicles. Proper, regular and timely maintenance during the life cycle of a vehicle, before repairs, can ensure not only the preservation of fuel consumption, at the original level of the new vehicle, but the very life of the vehicle itself.

Therefore, investment in repair shops and vocational schools to train mechanical workers to modern standards can go a long way in extending the life of the existing fleet in good and sustainable operating conditions. At the end of their life cycle, more materials should be reused or recycled. The waste resulting from scrapped vehicles consists mainly of metals, rubber, wood, textiles, glass or chemical and toxic liquids and up to 27 different types of plastic, all of which have the potential to be reused or recycled to some extent. This can be further boosted by mandatory recycled content rules for certain plastic components of new vehicles under the EU End-of-Life Vehicle Directive. [47]

5.3 The impact of dismantling used vehicles in Romania

In a world concerned with environmental and recycling issues, the automotive industry and the vehicles involved in everyday traffic generate an amount of debate, controversy ultimately resulting in a lot of plans and actions. Thus, the recycling of end-of-life vehicles (ELVs) is encouraged by a multitude of economic and technological factors, as well as social and ecological aspects of today's world.

In last years, the automotive industry in Romania is trying to move towards sustainable waste management and adopt this new way of doing business by adopting various programs. Moreover, the Romanian market is characterized by a large number of end-of-life vehicles (ELVs), which means that they are one of the most recycled consumer products. Thus, we can say that ELVs represent a category of waste from which different reusable materials can be extracted.

Along with the development of technology, new ingenious methods of using different materials in the construction of cars have also appeared. And through recycling, these resources can be recovered and reused to reduce pollution and reduce the carbon footprint generated globally.

Car waste can be recycled to the extent of 75-90%, so from an end-of-life car, through recycling, a number of elements can be reused, from the leather and textile materials used for the upholstery, to the steel present in the body. All of these are reused and reintroduced many times, also in the automotive industry. In fact, it is currently estimated that recycled metals make up about 25% of the amount needed to make a new car. So, car waste has an important role in the development of the high-performance models currently on the market.

5-1. Figure_ OVER 80% can be recycled from ELV's [www:recicling map.ro]

Dismantling motor vehicles involves removing all components that have an economic market value and selling them on the domestic market. Essentially, ELVs are vehicles that have reached the end of their life and are considered waste. ELVs are vehicles that are either old and unable to operate according to the manufacturer's terms, or are severely damaged in an accident. All ELVs are removed, or in the process of being removed, from circulation and of course decommissioned. There are two categories of vehicles that can be included in ELVs:

- M1 — all vehicles designed for passenger transport with less than 8 + 1 seats and
- N1 - all vehicles designed for the transport of goods, with a maximum load of less than 3.5 t.

According to car recycling statistics, more than 80% of the car can be recycled, and the remaining 20% that cannot be recycled is assimilated to the residues that can be chopped "auto shredder residue" (ASR). [48] Included in this category are ferrous and non-ferrous metal parts, paper, wood, rubber and plastic that are thrown into landfills. Worldwide, it is proposed to decrease the percentage of ASR, as approximately 5.5 million tons of ASR are landfilled each year. [49]

The automotive sector has been fulfilling its commitment to reducing the ecological impact of vehicle production and use since 2018. The automotive industry is concerned both with reducing waste and contributing to the modern approach to the circular economy, according to the European Association of Automobile Manufacturers (EAAM). The definition provided by Europa.eu states that "The circular economy is a model of production and consumption, which involves sharing, renting, reusing, repairing, refurbishing and recycling existing materials and products as much as possible. In this way, the life cycle of the products is extended. In practice, it means reducing waste to a minimum. When a product reaches the end of its life, its materials are preserved and reintroduced into the economy whenever possible.

In terms of waste management from the automotive industry, regarding the reduction, recycling and recovery of WEEE in Europe, it works well, but the Nordic countries, together with Switzerland, are considered leaders. These countries are considered leaders because they implemented early solutions for recycling this type of waste. After twenty years of handling WEEE, recycling and recovery rates are high and growing. Despite the new objectives to increase circularity introduced in a WEEE directive, in practice the focus is on handling EoL products as waste, and not as potential value in a circular system, while supply chain management is based on the flow of materials, the flow of money/value and the flow of information.

One recommendation is to harmonize the EU WEEE directive with the European Ecodesign Directive to align both directives with sustainability objectives, focusing on unifying the three dimensions — economic, environmental and social — as one (triple consumption), thus the problem recycling of WEEE will be raised from national to international level. [50]

Another recommendation would be to make a computerized ICT system a network, where each producer makes available their information related to WEEE throughout their life to ensure the flow of information in the reverse WEEE supply chain to strengthen producer responsibility.

5.4 National programs for ELVs recycling

For the correct collection of waste from the categories of electronic waste and end-of-life vehicles (ELVs), several national programs are implemented that offer benefits to car manufacturers in Romania.

For example, a program implemented that works very well and with good results offers a discount on the purchase of a new car battery when the replaced one is brought back to the center. These programs are only for car batteries, they do not work for e-waste batteries, these are currently collected in retail stores, but no benefits are offered to encourage proper collection and recycling.

Thus, the Environmental Fund Administration (AEF), coordinated by the Romanian Ministry of the Environment, launched the "E-rabla" program since 2018, to encourage the proper collection of WEEE resulting in a lower impact on the environment, to replace the old EEE , with higher energy consumption, with newer ones having lower energy consumption. The program offers a voucher that offers discounts on the purchase of new household appliances, of the same type as the one replaced, but with lower energy consumption. Until 2021, the Ministry of the Environment made available the "E-rabla" program - approximately 15 million euros - and it was estimated that more than 100,000 people will benefit from this program.

However, the subsequent information provided by the Romanian Administration of the Environment Fund (AEF) which implemented the "E-rabla" program shows that 43% of the money allocated by the Ministry through vouchers in the "E-rabla" program were returned to the budget, and they will be assigned at a later stage. In order for this program to be more successful among people, it would be useful for AEF to review the conditions for allocating vouchers for household appliances, respectively the way the project is implemented by the authorities.

The biggest program launched by AEF in 2005 is the program for the renewal of the car fleet called ***"Rabla"*** which is much more successful than ***"E-rabla".*** It has been operating for many years in Romania and it seems that it will continue in the coming years.

More precisely, this "Rabla" program for cars, which has been going on since 2005, is the main engine for the replacement, based on economic incentives (vouchers), of old vehicles with new ones, which significantly contributes to the support of the Romanian car industry. The positive influence of this program is more significant since 2007, when the target of reuse and recovery (85%) and reuse and recycling (80%) were met at the national level for 2007–2011, while in 2010 the number of ELVs collected had a strong increase in 2010 (197445) compared to previous years. Between 2005–2016, 553,334 vehicles were scrapped according to the Environmental Fund Administration (EFA) which oversees the program.

In the context in which the EU also recommends changing the car fleet by purchasing less polluting cars with lower emissions, the Romanian Ministry of the Environment has created a new program called "Rabla Plus" which offers, in addition to the vouchers obtained, a substantial premium for scrapping the car old, through the Environment Fund Administration, for the purchase of clean and energy-efficient cars.

Therefore, two main programs are currently operating — "Rabla Classic" and "Rabla Plus" — which are aimed at both individuals and economic agents. Any person with domicile or residence in Romania who owns a car older than 8 years and has no obligations towards the local budget can participate in these programs.

In order to obtain the scrapping bonus, old vehicles must have essential parts (engine, wheels, bodywork, etc.) and be made available to ELVs operators authorized to receive vouchers. Eco-bonuses (about 300 euros in Romanian lei) are available if new vehicles are less polluting by complying with certain parameters regarding the maximum emissions of propulsion systems:

- 96 g CO2/km NEDC stipulated in COC (Certificate). of compliance) in mixed mode of operation or engine system using compressed natural gas (CNG)/liquefied petroleum gas LPG;
- 105 g CO2/km, according to the Worldwide Harmonized Light Vehicle Test Procedure (WLTP standard) in mixed mode operation or engine system using (CNG)/LPG; and
- the maximum COC emission is 124 g CO2/km WLTP in mixed mode.

Conditions for accessing the Rabla 2023 program in Romania [51]:

For vehicles with combustion engine or hybrid without Plug-In

The RABLA program is based on awarding a ticket worth 7,000 lei for an old scrapped car, or 10,000 lei for scrapping two used vehicles.

The voucher can only be used for the purchase of a new car with emissions of a maximum of 155g CO2/km in the WLTP regime. A maximum of 2 RABLA tickets can be used for the purchase of a new car.

In addition to the amount of 7,000 lei, for an old scrapped car, respectively 10,000 lei for 2 old scrapped cars, the user can benefit from the following additional eco-bonuses if the conditions below are met:

- an eco-bonus of 1,500 RON, for the scrapping of each used vehicle that is at least 15 years old from the date of manufacture and which has a Euro 3 or lower pollution standard ("eco-age bonus").
- an eco-bonus of 1,500 RON, for the purchase of a car whose engine generates CO2 emissions lower than or equal to 120 g CO2/km in the WLTP regime.
- an eco-bonus of 1,500 RON for the purchase of a new car with LPG/CNG system.
- an eco-bonus of 3,000 RON for the purchase of a new hybrid car (without Plug-In).

Calculation example - the maximum financed value: when purchasing a car with an LPG system that has CO2 emissions lower than or equal to 120g CO2/km (WTLP) by scrapping 2 (two) 15-year-old vehicles with the Euro 3 norm, you can benefit from a maximum total discount of 16,000 RON: 10,000 RON Rabla ticket (2 scrapped cars), 2 x 1,500 RON (2 cars over 15 years old and Euro 3), 1,500 RON (eco-emissions bonus), 1,500 RON eco -bonus for vehicle with LPG system.

For 100% electric or hybrid vehicles with Plug-in technology (rechargeable)

For those who opt for a 100% electric or Plug-in hybrid car, the RABLA Plus Program offers the following types of tickets:

- an eco-ticket of 26,000 RON for the purchase of a new plug-in hybrid car with CO2 emissions lower than or equal to 80 g CO2/km in the WLTP regime, with the mandatory condition of scrapping one (1) old car.
- an eco-ticket of 29,000 RON, for the purchase of a new plug-in hybrid car with CO2 emissions lower than or equal to 78g CO2/km in the WTLP regime, with the mandatory condition of scrapping 2 (two) old cars.
- an eco-ticket of 51,000 RON for the purchase of a 100% electric car, with the mandatory condition of scrapping one (1) old car, but no more than 50% of the value of the new car purchased.
- an eco-ticket of 54,000 RON for the purchase of a 100% electric car, with the mandatory condition of scrapping 2 (two) old cars, but no more than 50% of the value of the new car purchased.

Within Rabla PLUS, the following scrapping premium can also be granted:

- an eco-bonus of 1,500 RON for each used vehicle that is older than 15 years and has a Euro 3 or lower pollution standard ("eco-age bonus").

The RABLA Classic and RABLA Plus programs cannot be accessed together.

Calculation example - maximum financed value: when purchasing a 100% electric car and scrapping 2 (two) old cars, the maximum total amount that can be benefited is 57,000 RON: 54,000 RON eco-ticket + 2 x 1,500 eco-bonuses of old age.

The growing concern regarding environmental protection leads to the development of an appropriate legislative framework regarding the recycling of automobiles, especially ELVs, it differs from one country to another, from one continent to another having common elements regarding environmental protection. The recycling of ELVs is subject to environmental protection laws in the European Union as well as in Japan, Korea, China and the USA.

In the following table we can see these differences between VLE management systems, either based on legislation or based on market mechanisms and environmental regulations. [52]

	ELV Management System	Background of the Management System
EU	Law/Directive 2005/53/EC (2000)	Measures for increasing automobile shredder residue (ASR) Measures for abandoned automobiles Environmental measures of dismantling sites
Romania	Law/Directive 2005/53/EC (2000) Law 212/2015 regarding ELV management "Rabla" governmental program	Measures for abandoned automobiles Environmental measures of dismantling sites, uses of resources, Bonuses for electric new cars bought
Japan	Law for Recycling of ELV (2005)	Lack of final disposal sites Illegal dumping of ASR Effective use of resources
Koreea	Law Act for Resource Recycling of Electrical/Electronic Equipment and Vehicles (2008)	Measures for ELVs Effective use of resources Management of information on ELVs
China	Law ELV Recycling Regulations (2001) Automotive Products Recycling Technology Policy (2006)	Measures for illegal assembly Effective use of resources Measures for recycling economy
USA	Related Law Resource Conservation Recovery Act, Clean Air Act, etc.	Strict implementation of regulations Environmental conservation measures associated with ELV recycling

Source: adapted after Sakai et al, 2014.

5-2. Figure_ Different Management Systems for ELVs

At the EU level, there have been concerns since 1970 regarding environmental protection, but a policy in this sense was adopted only after the Single European Act and the Maastricht Treaty. The legislative framework for the recycling of motor vehicles ELVs benefited from special legislation through the adoption of Directive 2000/53/EC, which aims to control waste from cars (recycling or disposal). The main tools considered are the

3Rs (Reduce, Reuse and Recycle) regarding the recycling of ELVs vehicles. The principles underlying this directive are:

- Subsidiary principle: legislation must be adopted by each member state at national level;
- Principle of responsibility: the car manufacturer and importers should bear the cost of recycling.

Both manufacturers and importers are responsible for:

- use of refrigerant in air conditioners;
- recycling of gas generators used for airbags and safety belt pretensioners;
- recycling and energy recovery of car shredding residues (ASR), using the recycling fee paid by new owners when purchasing a new vehicle.

The best action in the field of motor vehicle recycling was taken by the professional recycling industry, which focused on elements considered dangerous, such as dioxins, furans, polycyclic aromatic hydrocarbons, greenhouse gases and hexavalent chromium and mercury. In Romania, vehicle recycling and end-of-life programs are monitored in accordance with environmental laws.

Relevant state government regulations for end-of-life vehicle recycling and disposal are the Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Clean Water Act (CWA).

The Romanian CAEN code ("Classification of Activities in the National Economy") for the dismantling activity, 3831 and 3832, also includes waste activities and selective waste collection.

Due to the total lack of associations of the automotive industry, the Romanian market is more difficult to analyze. In 2004, ANSDAR (National Association of Auto Dismantling Societies) was founded and became a full member of EGARA (European Association of Automobile Recyclers in Europe). But this is no longer active, and the latest information indicates a number of 80 dismantling sites in Romania, processing approximately 20,000 cars per year (2009), and another 30,000 cars being completely disassembled by unlicensed sites.

The total share of the turnover is completely distorted because there are a large number of small-scale dismantling sites that do not accurately report their figure obtained from the recycling activity.

6 CIRCULAR ECONOMY vs. ELVs

If the auto remanufacturing business was exploited to its true potential, and did not depend on certain factors such as: the collection process and reverse logistics, the condition of the end-of-life vehicle, the additional cost of transport to the authorized service and the resources required until the disassembly and recovery of parts that can still be reused, then the vehicle industry through the modular redesign of components would increase the durability of products which denotes a sharp increase in recyclable products and materials, thus leading to the protection of the environment. But, in order to exploit this activity to the maximum, some shortcomings were identified, such as: the need for a continuous qualification of the staff and design engineers, the realization of an effective basic management, for the implementation of efficient and effective remanufacturing activities both in the light vehicle industry as well as in the heavy vehicle industry which must be supported by appropriate expertise, methods and tools.

Currently, end-of-life heavy and off-road vehicles do not have a well-defined management in Romania, they are not subject to strict regulations, which leads to the loss of valuable materials and recyclable electrical and electronic components with high added value. In addition, the durability of heavy vehicles is not studied in depth, being a new field of research, compared to the light vehicle industry that regulates end-of-life (Directive 2000/53/EC) by imposing mandatory recycling and recovery activities, thus managing how decommissioning of heavy vehicles is a barely addressed problem. Thus, in order to achieve a circular economy (CE) regarding the management of heavy and off-road vehicles at end-of-life, an appropriate circular strategy must be implemented, supported by regulations and obligations, or the implementation of appropriate programs through the considerable motivation of users. In Romania, significant quantities of such heavy and off-road vehicles are registered, achieving a real economy, if the management of the way to remove them from use were set up by collecting and storing them in appropriate spaces, the expansion of authorized services for dismantling through the recovery of reusable components and parts resulting in this field as well a circular economy by closing the loop, namely: the maintenance, reuse, remanufacturing and recycling of these vehicles.

However, such an economic model has not yet been validated in Romania, currently this heavy industry faces a lack of infrastructures, methods and support materials to do so. When the processes to design the parts are poorly done and often dimensioned incorrectly and the disassembly processes are cumbersome and laborious requiring resources and a long time to achieve them. Furthermore, the complexity of this industrial sector, plus its considerable environmental and economic impact, makes it particularly relevant from a research perspective to find out how to implement circular practices. As such, OEMs in the heavy duty and off-road vehicle industry recognize the potential of CE models to increase the value of their products and materials and mitigate the risks associated with volatile material prices and supplies.

Currently, the end-of-life road vehicle industry is subject to strict regulations, which closes the loop on achieving a circular economy by: *The european green deal and the circular economy on E-WASTE*

The European Green Deal has been published by the European Commission since 2019. This pact is "an initial guide to key policies and measures" aimed at transforming the EU "into a fair and prosperous society with a modern, efficient and competitive economy from the point of view of resources". Among a number of goals and actions, the communication envisaged a "new action plan for the circular economy". In a circular economy, products and the materials they contain are highly valued, which means minimizing waste, keeping materials in the economy as much as possible.[53] This would include prioritizing reducing material use and increasing reuse over recycling, and would involve strengthening extended producer responsibility.

In March 2020, the Commission published "A new circular economy action plan - For a cleaner and more competitive Europe”.[54] It identifies electronic equipment and information and communication technology (ICT) as one of the key value chains requiring "urgent, comprehensive and coordinated action".

The Commission plans to present a "Circular Electronics Initiative" in the fourth quarter of the year 2021 [55], aiming to promote the life of the products, the following [56]:

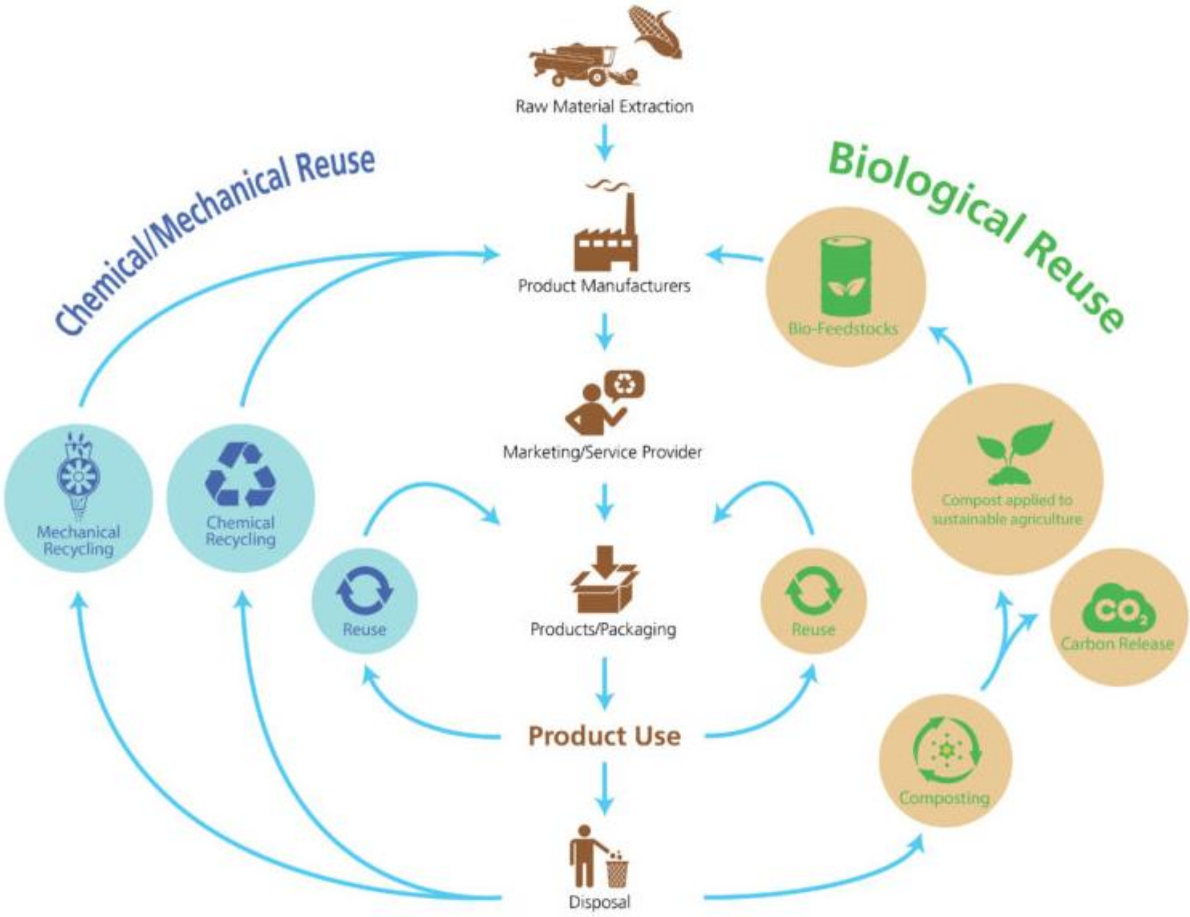
- regulatory measures covering the design of electrical and electronic equipment, aimed at improving their energy efficiency, durability, repairability, modernization, maintenance, reuse and recycling;
- prioritizing electronic and ICT products to implement a "right to repair" policy, including the right to update outdated software;
- regulatory measures regarding chargers for mobile phones and similar devices;
- improving WEEE collection, including by exploring an EU-wide take-back system for old mobile phones, tablets and chargers;
- a review of EU rules on hazardous substances in electrical and electronic equipment.

6.1 Principles of a circular economy

In a world full of limited resources, manufacturers of electrical and electronic equipment must adapt to the new provisions and adopt sustainable practices that benefit both consumers and the planet.

In the past, most products from the automotive industry were designed to be used only once and then with the disposal of end-of-life vehicles disposed of in designated areas. As warehouses reach capacity, the need for change is imminent.

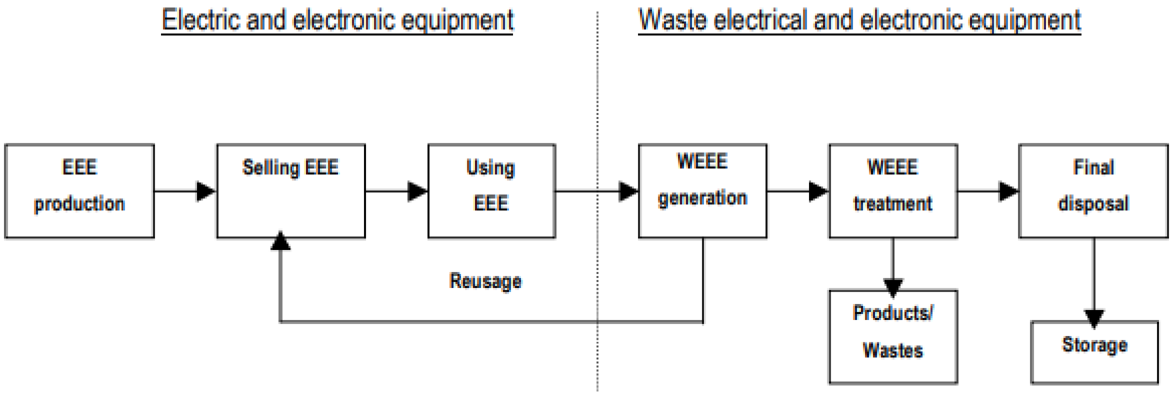
A circular economy involves recovering and reusing products in a continuous loop rather than throwing them away. Products that cannot be reused will be recycled through various procedures or processes.



6-1. Figure_ Circular Economy [https://circulesolutions.com]

The transition to the circular economy can also be improved by encouraging investments in eco-innovation through the design of reusable products with an extended life cycle, the use of alternative energies, resource efficiency, ensuring selective collection infrastructure in urban and rural environments. Carrying out actions to raise public awareness about the importance of selective waste collection; through the correct implementation of already adopted European legislation, both at local and national level, improvements related to the adoption of the "3 R" for both the public and private sectors.

According to Article 3, of Directive 2002/96/EC, letter b, waste electrical and electronic equipment is "electrical and electronic equipment as waste, including components, subassemblies and consumables that are an integral part of the product when they become waste", the management of this solid waste categories require a specialized collection, transport, treatment and final disposal system. Understanding the mechanisms and operating principles of this type of WEEE management system can only be possible after a careful identification and analysis of the life cycle of EEE from the production phase to the final waste disposal phase as a result of physical wear and morale of this equipment. [57]

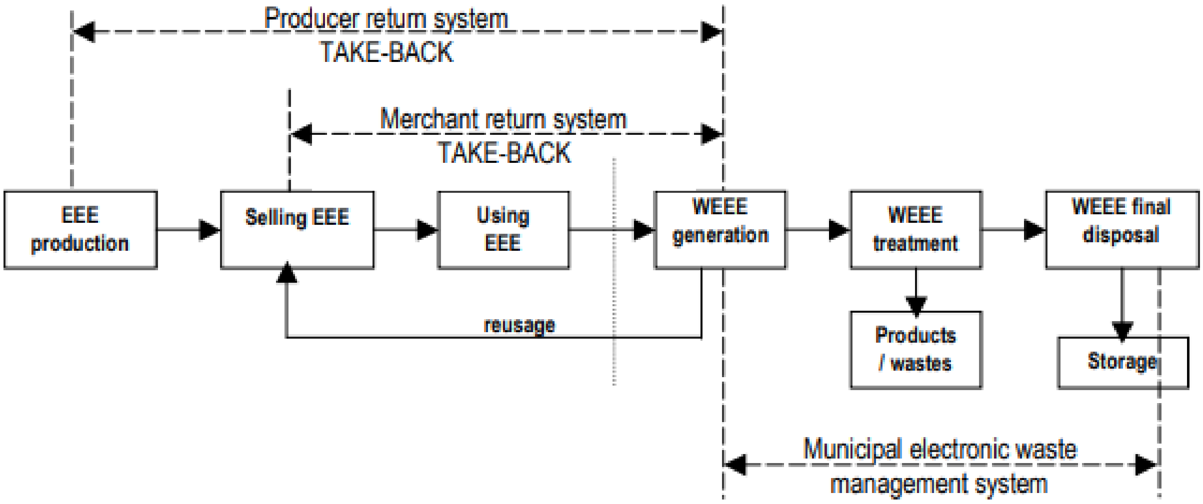


6-2. Figure_ WEEE life cycle [28]

Thus, WEEE management includes 3 major components:

1. WEEE collection, sorting and transport system,
2. WEEE treatment system,
3. WEEE final disposal system.

In the practice of developed countries, the existence of three main collection channels is specified, with special results both in terms of effectiveness and efficiency of collection.



6-3. Figure_ Main weee collection channels [28]

In accordance with the principles of a circular economy, vehicle recycling has become the direction of development of the vehicle industry in Romania. Car recycling infrastructure and subsequent technologies comprise a major industrial focus that has been sustained and developed in recent years.

Thus, the car construction sector contributes 1% to the national GDP. In terms of exports, this sector is the third strongest. However, during the COVID 19 pandemic, the sector's turnover fell for the first time since 2011 to €4.3 billion. The greatest potential for circularity lies in the increased use of recycled materials, in increasing the share of machines, machine components and materials that are reused, repaired and recycled, and in the use of new and innovative technologies in the production process. [58]

The high energy consumption of the automotive sector and the greenhouse gas emissions resulting from the production of passenger cars are one of the two main challenges. This is the result of the traditional and conservative way of production, for example, by means of mechanical drives powered by carbon-emitting diesel or petrol.

Like other EU countries, Romania must face the challenge of defossilizing the energy system used in the industrial sector and, consequently, in the car construction sector. This involves switching to renewable energy sources instead of fossil energy sources. While this shift contributes to progress towards a more circular economy, the cost-effectiveness of renewable energy sources remains an obstacle to maintaining profitability.

Another challenge is that the use of recycled materials is not advanced - only 14% of the raw materials used in the industry are of recycled origin. [59]

To promote the circular economy in the car construction sector, in the design phase, cars and their components should be designed for easy and efficient disassembly. In this way, defective parts could be easily disassembled and removed for replacement, extending the life of the machine through easier repair. In the production phase, by applying new operating technologies that are efficient in terms of resources and materials (low-carbon), as well as low-carbon fuels such as hydrogen or switching to electric powered motors of batteries or fuel cells. [60]

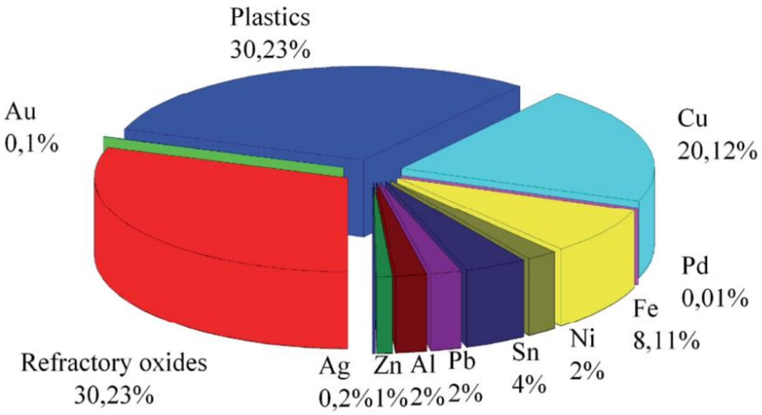
Innovations that support self-maintenance, disposal and sorting processes promise additional opportunities. In the end-of-life phase, activities such as repair, reuse, remanufacturing as well as recycling of machines, machine components and materials should be encouraged and promoted as far as possible, taking into account the appropriate treatment of hazardous substances. In parallel, to stimulate both supply and demand, requirements and economic incentives can be established to encourage the use of recycled materials in the production process.

Corporations, including car manufacturers, are increasingly exploring extensive circular economy strategies as a means of increasing the sustainability of their products. The circular economy paradigm focuses on reducing non-renewable materials and energy, promoting renewable raw materials and energy, and keeping products/materials in use throughout the life cycle of a system. As such, the life-cycle environmental burdens associated with the manufacture, use and disposal of vehicles could be reduced through circular economy strategies.

Thus, 75% of a used car can be recycled nowadays. In order to recycle the parts, it is necessary to collect, treat and dismantle the end-of-life vehicles, including those destined for the renewal of the "Rabla" national self-program park.

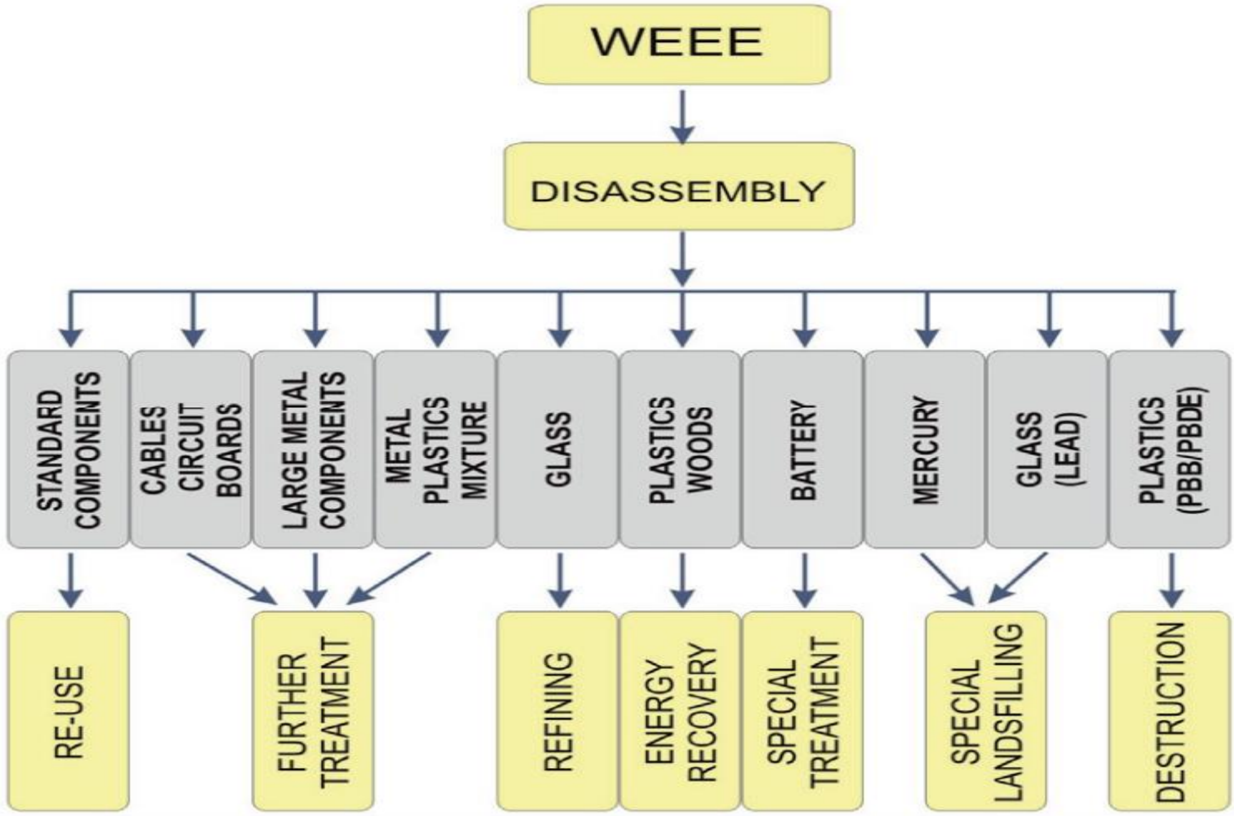
One of the important problems in the treatment of WEEE is the content of substances such as heavy metals and organic compounds. In combination with halogens in the plastic fraction they can form volatile metal halides but they also have a catalytic effect on the formation of dioxins and furans. [61]

WEEE are composed of metal (40%), plastic (30%) and refractory oxides (30%) [9]. As shown in the next figure, the typical metal scrap consists of copper (20%), iron (8%) tin (4%), nickel (2%), lead (2%), zinc (1%), silver (0.02%), gold (0.1%) and palladium (0.005%). Polyethylene, polypropylene, polyesters and polycarbonates are typical plastic components. [62]



6-4. Figure_ Characteristic material composition of WEEE [62]

Incoming electronics are manually sorted to the product groups or directly transferred to another recycling entity. Products may be transferred if they are still functional, or exceed the recycler's capacity, capabilities, or permits. Products accepted for processing are sorted and staged for disassembly. [63]



6-5. Figure_ Typical recycling process of WEEE [64]

The recycling activity consists of:

- **extraction** from the used vehicle of remaining fluids such as oils, fuel, refrigerant, brake fluid, antifreeze, windshield fluid but also used batteries (these are stored in airtight containers, for delivery to companies authorized for recycling)
- **removal** of vehicle parts such as tires, transmission, car batteries,…
- i**ntroductio**n in the shredder installation (their processing by crushing and separation of ferrous and non-ferrous metal waste, of recyclable metal waste of non-recyclable one)
- the **electric cables** from the dismantling activity are processed through the electric cables recycling line, installation with the help of which the separation of non-ferrous waste from plastic (PVC) takes place

As the metallurgical industry relies heavily on resources that are scarce in Europe, circular economy principles could help address the decoupling between virgin material extraction and economic growth and provide environmental benefits. The greatest potential for circularity was observed in the design phase in terms of the implementation of eco-design criteria and requirements, the improvement of technologies in the production phase and in the end-of-life phase in terms of more recovery was found large amount of materials. The main challenge to making the metal industry more circular is the low demand for low-carbon materials, which limits the adoption of recycling. Thus, the ferrous and non-ferrous material is sold to recyclers in the metallurgical industry, being reintroduced, after processing, into the economic circuit. The non-recyclable material is handed over for recovery by incineration to companies specialized in this regard. The company that received the recycled material issues a certificate of destruction for the delivered vehicle, according to the legislation in force.

Furthermore, of those materials that are recovered, most are not recycled to their full potential due to several problems in the value chain, such as imperfect collection and sorting systems that prevent end-of-life metals from reaching recyclers ; or the increasing complexity of products, miniaturization and mixing of metals, which lead to increased complexity of recycling.

This challenge becomes even more pressing if we consider that chemical, metallurgical and steel waste is the second largest contributor to the total waste generated by the processing industry (about 39%). About 25% of the waste from the chemical, metallurgical, steel and printing industries is recovered, but the rest is stored in dumps formed in excavated land, threatening the local ecosystem.

Currently, more than 25 million tons of waste generated by obsolete cars are collected annually in the world. A non-functional car is 75% recyclable.

Ferrous and non-ferrous waste are returned to the economic circuit, tires are used to produce asphalt, plastic is returned as a raw material in various industries. Recycling processes consume less energy than the initial production of a car's components.

<u>Metallic and non-metallic waste</u>: 90-95% metal scrap can be recycled!

Non-ferrous metal waste (aluminum, copper, etc.) is recycled in a proportion of over 90%. There are compounds that can be recycled indefinitely, without losing quantity. The aluminum recycling process, for example, saves 90% more energy than the initial production of raw materials.

Electrical and electronic waste

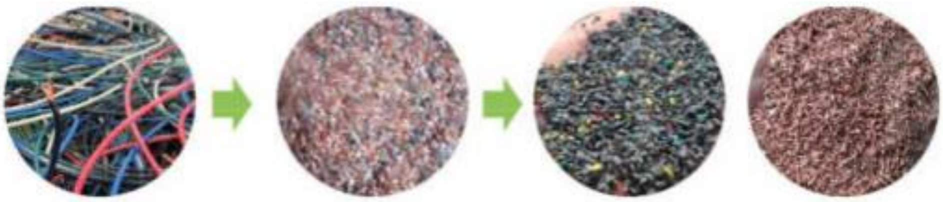
Represents all obsolete electrical and electronic equipment that operated on the basis of current or with the help of batteries: Computer board, Phone board, TV board, CCL (copper-clad plate), PCB leftover material, etc.

6-6. Figure_ Typical recycling process of WEEE

Final Products: Mixed metal powder, Resin fiber powder

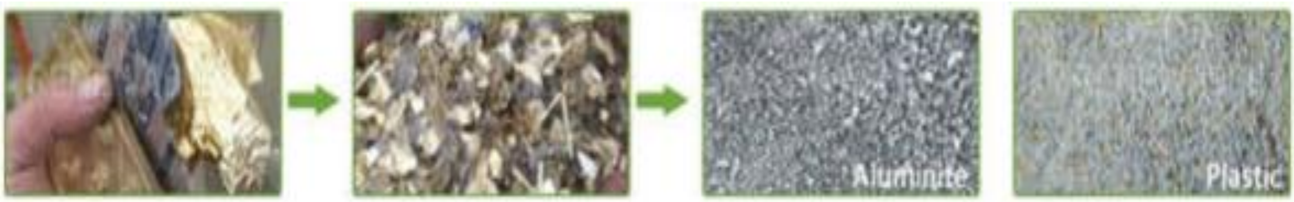
Applicable materials: chips, north and South Bridges, memory chips, integrated circuits, plastic components, anode mud, etc.

They contain substances dangerous for the environment or health but also large quantities of secondary raw materials; have a high degree of recycling / reuse (85-90%).



6-7. Figure_ Mixed metal powder, Resin fiber powder

Plastic is considered the hardest to recycle, most severely affects the environment and consumes an impressive amount of oil for production. Only 5% of the amount of plastic waste can be recycled efficiently and 40% inevitably end up in the landfill.



6-8. Figure_ Mixed aluminum powder, plastic powder

Glass, although the most difficult to decompose in the natural environment (in a million years) is a 100% recyclable waste. Also, recycling costs are lower than those for the production of glass from raw materials.

Glass can go through the recycling process indefinitely without losing its purity or quantity. Currently, a glass product is formed, in proportion of 70% of recycled glass.

Paper and cardboard can be recycled almost any kind of paper and cardboard, but sometimes not indefinitely; paper and cardboard stained with oil and food cannot be recycled; new cellulose fiber uses 40% more energy to produce than recycled paper, which is why paper is also a favorite recyclable product and because the paper recycling process produces 70% less pollution.

By reducing the amount of paper that reaches landfills, we also reduce global warming, because, although the paper decomposes in 5 years, it releases into the atmosphere a compound, methane, a greenhouse gas, 21 times more dangerous than carbon dioxide. carbon. A ton of recycled paper saves 17 trees from cutting.

Auto-waste materials from car batteries and accumulators have the highest recycling rate of all existing products (approximately 99%).

Edible oil waste - from used food fats can be made soaps, candles or biodiesel fuel.

As vehicle manufacturers, it is very important that at the end of the life cycle of cars, they reduce as much as possible the impact on the environment. For this reason, manufacturers are focused on the three "R" pillars: reduction, reuse, recycling.

The targets set by the European directive for 2015 are the recovery of 95% of the average weight of a vehicle per year and the recycling and reuse in proportion of 85%, leaving only 5% of the car.

Vehicle manufacturers should achieve the following objectives:

- Design and production of cars from which materials can be recovered;
- Recovery of used car parts and components that can be replaced during the life cycle of a car;
- Waste minimization (cars at the end of the life cycle);
- Free collection (except for the administrative costs of canceling RAR and transporting the authorized collection centers) at the end of the life cycle of the car.

There are 21 authorized agents in the country for taking over end-of-life vehicles.

6.2 CIRCULARITY OF WEEEs

The Government of Romania approved, in 2022, the Strategy for the Circular Economy in which 7 sectors with increased potential are targeted, including the Electrical and Electronic Equipment sector.

To promote the circular economy in the car construction sector, design phase, cars and their components should be designed for disassembly. In this way, defective parts could be easily disassembled and removed for replacement, extending the life of the machine through easier repair.

Another opportunity is at the production stage, by applying new resource-efficient operating technologies and low-carbon materials, as well as low-carbon fuels such as hydrogen or switching to electric motors powered by batteries or fuel cells. [65]

In the case of electrical equipment and electronic products, the national issue is related to separate waste collection infrastructure. In 2019, only 27% of electrical and electronic equipment placed on the market were collected in Romania, the lowest rate among EU member states.

The most important changes are needed in the design and use phase, by applying eco-design and sustainable production of EEE, as well as sustainable consumption by reducing the volume of e-waste generated through reuse and repair.

This should be supported by better customer information and awareness, increased producer involvement and customer information and education.

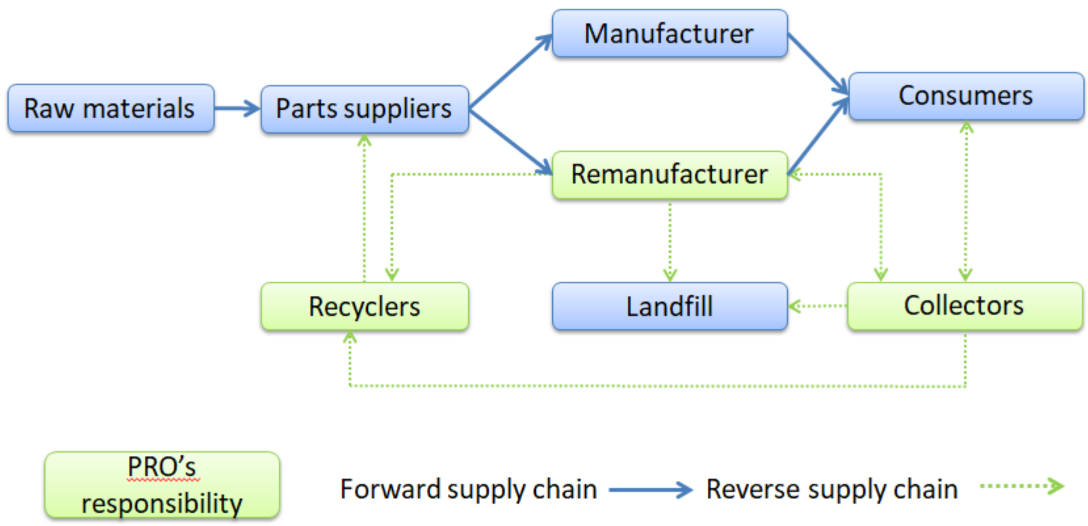
Moreover, local authorities, in partnership with social enterprises, social insertion enterprises and NGOs, should create and support repair systems and create a platform for reused products for companies.

Also, local authorities can support technical schools to learn the trade of electromechanics, electricians.

At the same time, local authorities should carry out campaigns to inform citizens about the benefits and risks involved in not properly collecting and storing waste electrical and electronic equipment.[60]

Reverse supply chain management is defined as carrying out the activities necessary to take a used product from a customer and recycle it either by disposal, reuse or partial recovery.

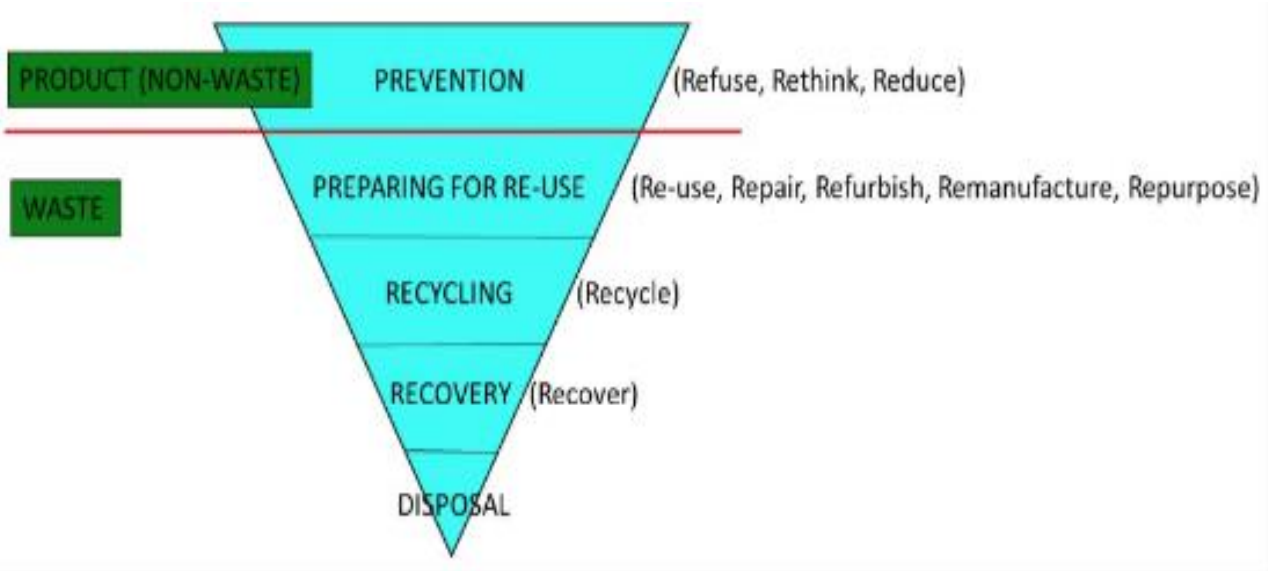
In the context of a circular economy, the objective should be to achieve as high a level of circularity as possible, i.e. in an open-loop supply chain, the actors who introduce products to the market are not the same as those who take the products after use for reuse/ recovery, while in a closed circuit the actors are the same. [66]



6-9. Figure_ Material flow in a supply chain

In order to carry out the disassembly regarding the recycling of certain components, special knowledge is required, thus establishing various companies specialized in the disassembly and recycling of products from the automotive industr. [67] In 2017, in Romania, an EcoTree platform was established, for collaboration between manufacturers, suppliers and recyclers, regarding the products that can be recycled, the list of materials, types of parts, disassembly methods and recycling analyses.

In the EcoTree platform, generators with recycling needs can more easily identify suppliers: collection companies, recyclers, sanitation workers, waste sorting centers, NGOs, in such a way as to find the most suitable solution for their company and for their needs management of the waste they have. In addition, the platform provides a framework for special auctions, while digitizing the processes of recycling and submitting the necessary legal documentation.



6-10. Figure_ EU's waste hieraracy and circular strategies

[Directive 2008/98/EC on waste (Waste Framework Directive)]

The Green WEEE International recycling plant in Buzău is the largest waste electrical and electronic equipment (DEEE) recycling plant in Romania and one of the most important in Central and South Eastern Europe.

WEEE is the fastest growing waste stream in the world, with more than 56.2 million tonnes being generated in the market every year. Less than 20% of this is officially recycled, with the remaining 80% ending up either in landfill or in informal streams.

In Buzău and Câmpia Turzii factories, over 100,000 tons of electrical and electronic equipment become, every year, a source of secondary raw materials. Thus, over 98% of the materials are recovered within the factories, contributing to the conservation of natural resources and the promotion of the circular economy. E-waste is becoming more and more valuable, being used as a secondary raw material in the manufacture of new products.

"From one ton of copper ore you extract 0.5% raw material, around 5kg of copper, (…) with significant investments and a huge impact on the environment while cables contain 10% copper (…) from a 100 kg of copper is recovered per ton of cables. (…)

In mobile phones there are around 70 elements from Mendeleev's table that can be recovered, (…)" [68]

Depending on the category to which the waste belongs, it is placed on different disassembly and treatment lines, resulting in several categories of secondary raw materials that can be transported later to smelters or manufacturers in various industries:

- copper: granules and wires from cable processing, copper parts, parts of copper cables
- aluminum: aluminum granules resulting from cable processing, shredded aluminum from refrigerators and coolers, from various WEEE
- shredded iron from refrigerators, from various WEEE
- fractions of non-ferrous materials representing the base of the lamps
- printed circuit boards, shredded from WEEE – contain copper and precious metals (gold, silver, palladium)
- radiators (contain copper, aluminum and iron)
- WEEE mix material - contains copper and precious metals (gold, silver, palladium)
- electric motors
- various types of shredded plastic (ABS, Polypropylene - PP, PVC, Polyethylene - PE, etc.)
- glass from WEEE, glass from lamps

6.3 Zero waste & Circular economy

Zero waste and the circular economy are two different models that take approaches to sustainability, reducing greenhouse gas emissions and ultimately climate change. The impact on the environment by generating less waste is achieved through more efficient resource management. This management is crucial to our efforts to reduce these impacts.

Thus, the European Commission adopted in December 2015, a package of measures aimed at stimulating Europe's transition to a circular economy. This package of measures includes proposals for revising the legislation on waste, as well as a related action plan. The waste proposals establish a long-term vision for minimizing waste generation, increasing recycling quantitatively and qualitatively, by re-introducing waste into the economy in the form of secondary raw materials, thus reducing the use of resources and by reducing landfill disposal.

The directives that will be revised following the adoption of the circular economy package are:

- Directive 1999/31/EEC on waste storage
- Directive 2011/65/EC on restrictions on the use of certain hazardous substances in electrical and electronic equipment
- Directive 2012/19/EU on waste electrical and electronic equipment
- Directive 2000/53/EC on end-of-life vehicles

The circular economy action plan complements these proposals by establishing measures aimed at closing the circular economy loop and targeting all stages of a product's life cycle: from production and consumption to waste management and the market for secondary raw materials. (ANPM)

Among the main proposals for revising the legislative framework included in the Circular Economy Package is included, among others, the granting of Economic Incentives for producers to put more ecological products on the market and the support of recycling and recovery schemes (for example for packaging, batteries, electrical equipment and electronics, vehicles).

The National Legislation on special waste streams includes, among others:

- Law no. 212/ 2015 regarding the way of managing vehicles and end-of-life vehicles
- GEO no. 5/02.04.2015 regarding electrical and electronic equipment waste
- HG no. 1132/2008 regarding the regime of batteries and accumulators and battery and accumulator waste, with subsequent amendments and additions
- HG no. 170/2004 regarding the management of used tires.

Among the main objectives in the waste management sector provided for in the legislation are:

Regulatory act	Obiectiv Objective	Deadline
OUG no. 5/2015	EEE producers have the obligation to ensure a collection rate of at least 65%	Start 2021
HG no. 1132/2008	Collecting at least 45% of the waste batteries and portable accumulators	Yearly
Law no. 212/2015	Economic operators authorized to carry out treatment activities of end-of-life vehicles are obliged to ensure, for all end-of-life vehicles taken over for treatment, the achievement of the following objectives: • reuse and recovery of at least 95% of the average weight per vehicle/year; • reuse and recycling of at least 85% of the average mass per vehicle/year.	Anual

HG no. 170/2004	Legal entities that introduce new tires and/or used tires intended for reuse on the market are obliged to: a) collect used tires, within the limits of the quantities they introduced on the market in the previous year; b) reuse, re-use as such, retread, recycle and/or thermally utilize the entire amount of used tires collected.	Anual

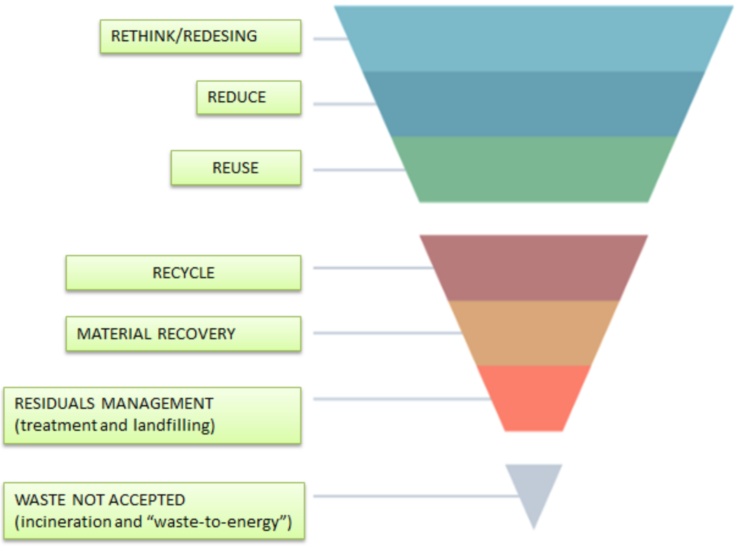
Source: National legislation

The competent authority in the field of waste management is the Ministry of the Environment, and the institutions under coordination are:

- National Agency for Environmental Protection (ANPM);
- National Environmental Guard (GNM);
- Administration of the Environment Fund (AFM).

Achieving **Zero Waste** focuses on "conserving all resources through responsible production, consumption, reuse and recovery of packaging and materials, without burning them and without discharges into soil, water or air that threaten the environment or human health."

In order to achieve zero waste, we must return to the design phase to realize a product design in such a way that it is possible to recover as many components as possible, taking into account that toxic substances do not reach the environment.



6-11. Figure_ Zero Waste- ranking

Since the 1980s, people have become aware of how many resources are ending up in landfill. Thus, in the following decades, to minimize waste through reduction, reuse and recycling, both local and governmental legislative changes occurred. To meet these changes many companies have pledged to become "zero waste" by a certain date to show their commitment to sustainability.

In contrast, the **Circular Economy** is a concept that promotes the design of closed-loop systems through the circularity of resources so that raw materials remain in the loop. Circular economies eliminate waste by designing and creating more efficient systems that take into account the entire life cycle of a product, ensuring that the resulting waste is of the highest possible quality so that natural resources can be reused.

The concept of the circular economy first emerged in the 1960s, when environmentalists and academics were concerned with environmental pollution and the exploitation of natural resources, emphasizing clean renewable energy and managed water systems to promote healthy ecosystems.

The circular economy model has three main principles that are more like pillars that work in tandem: designing for waste and pollution, keeping products and materials in use throughout their lifetime, and regenerating natural systems. While zero waste focuses on keeping waste out of the environment, a circular economy goes a step further by striving to protect the environment.

Thus we can say that zero waste is a set of principles that guides us towards a goal, while a circular economy is a model that provides a systematic framework. We can also think of zero waste as a goal and a circular economy as a means to get there.

In this way, we can see that these two concepts are different but complement each other in multiple ways.

<u>Our role in a circular economy</u>

It is much easier to incorporate zero waste principles into everyday life than to build a circular economy. While some of the methods involved - reduce, reuse and repair/recycle - are part of both, for the most part, it is not realistic for a single person or family to develop their own circular economy.

Anyone can even participate in a circular economy with goods they already own. Gadgets and technology are great components to start with, for example repairing broken screens or when it's time to upgrade, one option is to recycle old smartphones or donate them. The same principle can be applied to electrical and electronic equipment intended for command, protection, adjustment and automatic or non-automatic control of the operation of electrical installations in the automotive industry.

<u>The benefits of a circular economy</u>

The benefits of adopting circular economy principles include, among others:

- reduced need for natural resources, energy, water consumption and waste production;
- reduced carbon emissions;
- reduced effects on the environment;
- reducing waste by promoting the recycling of finished products;
- fewer price increases; and

premium IT equipment at an advantageous price.

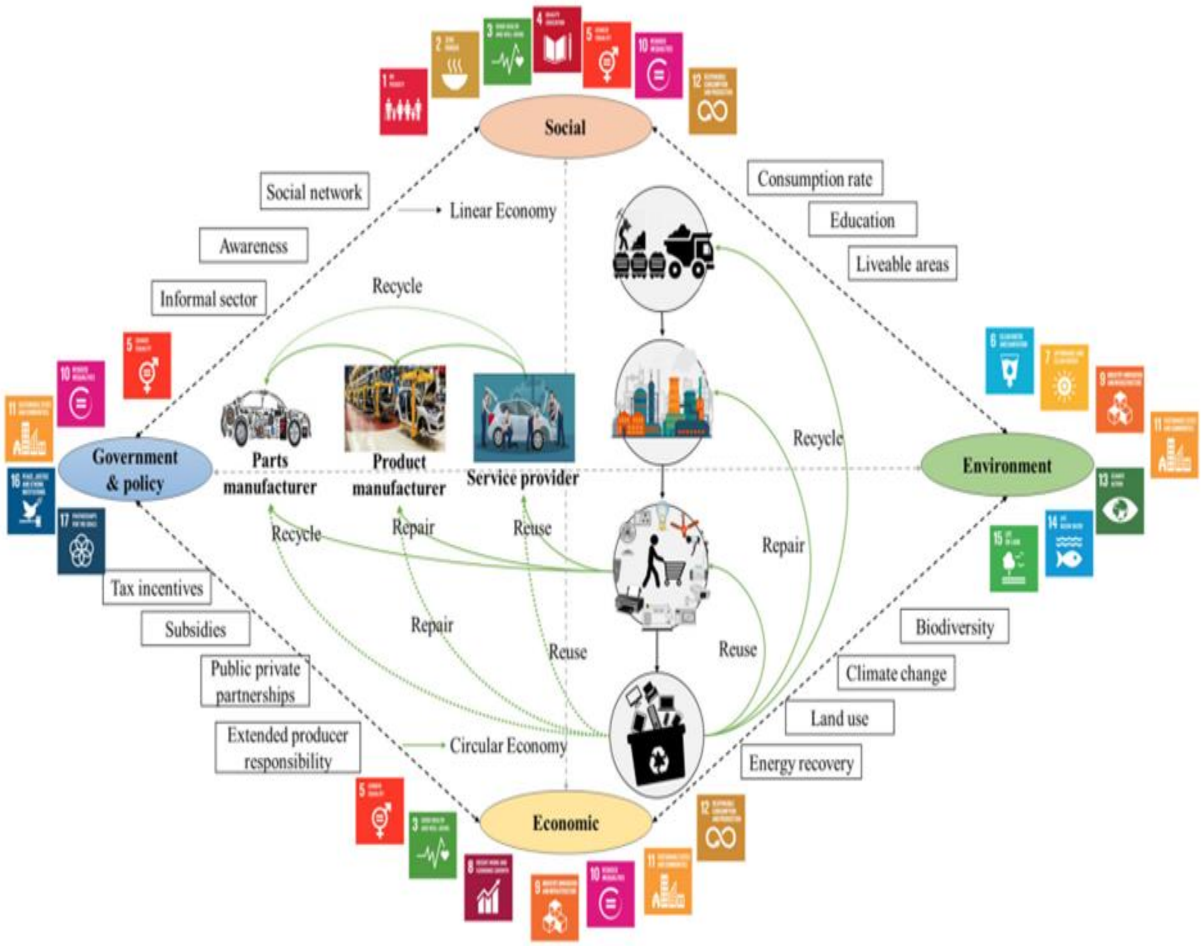
6.4 Objectives and directions

The National Waste Management Plan in Romania established, among others, the following collection and recycling objectives until 2030:

- Recycling 55% of municipal waste by 2025 and 60% by 2030.
- Recycling 65% of packaging waste by 2025 (plastic 50%; wood 25%; ferrous metals 70%, aluminum 50%, glass 70%, paper and cardboard 75%) and 70% by 2030 (plastic 55% , wood 30%, ferrous metals 80%, aluminum 60%, glass 75%, paper and cardboard 85%).
- Separate collection of household hazardous waste by 2022, bio-waste by 2023 and textile waste by 2025.
- Establish mandatory extended producer responsibility (REP) systems for all packaging by 2024.

The key objectives of the National Circular Economy Strategy provide the framework that guides Romania's efforts to transition to the Circular Economy through the implementation of the Action Plan. They also serve to define the most important elements and areas within EC applied in Romania, thus aligning the expectations and visions of all parties involved.

EC promises to build a resilient system that will benefit businesses, people and the environment, resistant to the effects of climate change or global supply chain disruptions.



6-12. Figure_ Circular economy approaches in management of electronic waste [(https://www.sciencedirect.com/science/article/pii/S0048969721046805)]

Economically, E-waste is an ‘urban mine’ with the potential to recover several precious, critical, and other noncritical metals (Iron, copper, and gold) that, if recycled, can be used as secondary raw materials. [69]

In accordance with the relevant national strategies aimed at a sustainable, ecological and fair Romania, the following key objectives are established:

1) Prioritizing local production over imported products and materials;
2) Strengthening economic competitiveness and the labor force;
3) Responsible and sustainable supply of raw materials;
4) Priority promotion of innovation and research in the field of circular economy;
5) Preservation, conservation and sustainable use of natural resources;
6) Prevention of waste generation and sustainable waste management;
7) Promoting responsible consumption and environmental education;
8) Protection of ecosystems and citizens' health.

Based on the key objectives, the following directions must be followed through the development of policies to advance the Circular Economy in Romania. These must be addressed through regulations, economic incentives and measures that will be introduced in detail in the Action Plan. The measures will be established based on the legislation in force, at national, community and international level, and will not affect biodiversity or human health.

Reducing the consumption of virgin raw materials through more sustainable extraction of raw materials and through recycling and recovery activities.

II. Reducing the consumption of consumer goods by extending the life of products:

- application of circular design and material efficiency;
- promoting dematerialization.

III. Reducing the impact of production activities on the environment by:

- application of more innovative and ecological technologies and processes;
- promoting digitization;
- favoring renewable energies at the expense of fossil fuels;
- exploiting the potential of industrial symbiosis.

IV. Reducing the environmental impact of waste and wastewater management and disposal activities by:

- promoting waste prevention;
- improving the waste management system and infrastructure;
- promotion of waste sorting and treatment activities;
- limiting waste storage to a minimum.

V. Improving policy coherence and governance, communication and collaboration between local, regional and national authorities.

Source: World Bank. 2023. Diagnostic Analysis for Circular Economy Interventions in Romania. © World Bank.

6.5 Local best practice

In Romania there are some examples of good practices regarding the separate collection of waste at regional level. Several cities in Romania, with development potential, have implemented the transition process towards a circular economy for sustainable development, namely:

1. Cluj – by realizing the Smart City through the National Fund for the Development of Information and Communications Technology (TIC), with the highest absorption rate of European Funds;
2. Oradea – through Infrastructure Development and Digitization of the city in order to increase the quality of life, with a high absorption rate of EU funds;

3. Buzău - by establishing Partnerships in order to obtain the best Waste Management System. Buzau being the first city with a local strategy.
4. Iași - the first Municipal Waste Collection Center in Romania (2016), built and operated according to European standards, participates in improving the methods of collecting recyclable waste and reducing the negative impact on the environment, especially by collecting waste from electrical equipment and electronics (WEEE).

In conclusion, the benefits of the circular economy are:

- Protecting the environment;
- Reduces dependence on raw materials;
- Increases the efficiency of resource use, including financial savings;
- Generates opportunities for new business models;
- Generates new jobs;
- Stimulates economic development in a broader sense through innovation and increased competitiveness;
- Supports local development, using more of the resources in the vicinity.

Source: World Bank. 2023. Diagnostic Analysis for Circular Economy Interventions in Romania. © World Bank.

In this paper, a wide variety of recycling processes have been highlighted, allowing the recovery of most component parts from the disassembly and recycling industry of ELV's, allowing the recovery of any part or material from a discarded product. Currently, many valuable materials and metals are lost due to poor, defective collection of end-of-life vehicles, and this prevents us from achieving our goals of achieving a high recycling rate in the automotive industry nationally.

A major increase in the recycling rate could be achieved by:

- Improving the methods of collecting waste from electrical and electronic equipment (WEEE).
- Prevention of losses in the preprocessing stage. (eg PCBs should be removed at an early stage and provided to appropriate metallurgical recovery processes)
- Recovery of metals used in coatings can be greatly improved by processing waste streams from plating operations.

7 DISCUSSION THEMES

1) Explain the meaning of abbreviations ELV's and WEEE, and in what fields should ELV's be considered.

3) Explain what the 5 responsibilities are if you manufacture, distribute or sell electrical and electronic equipment.

4) Explain what are the criteria for classifying electrical and electronic appliances.

5) Explain what the 3Rs mean, and mention the most important directives related to ELV's and WEEE in Ro.

7) Mention what is the common point between WEEE and ELV's, and explain what WEEE is composed of.

9) State what the WEEE recycling activity consists of, and list five types of automotive waste.

11) Define WEEE according to Article 3 of Directive 2002/96/EC.

12) Mention two examples of good practices from Ro, and name five examples of recycling methods.

14) Explain what ASR means, and mMention what is the percentage of ASR in ELV weight.

16) Define the classification of non-ferrous metals according to density.

17) The mentioned two examples of separation technologies.

18) State what is the main purpose of recycling electrical cables.

19) State what pyrometallurgical treatment is used for.

20) State what hydrometallurgical treatment is applied to.

21) Define electrochemical treatment methods. Mention what they are performed with.

22) Mention which are the categories of vehicles that can be included, regarding the impact of dismantling ELV's.

23) Mention what is the disassembly percentage of an ELV.

24) Specify what was the first national program for ELV's and in which year it was launched, and name the current national programs and explain what types of vehicles each applies to.

26) State in which city the Green WEEE International recycling plant in Romania is located.

27) Mention what Law no. 212/ 2015, and GEO no. 5/02/04/2015.

28) What are the principles of the circular economy? But zero waste?

29) State a parallel between the circular economy and achieving zero waste.

30) State the benefits of a circular economy.

8 QUIZE

To answer the questions correctly, select only the correct answers.

[1]. In the paper, ELV's is defined as:

a) a vehicle that has become junk,

b) scrapped vehicle,

c) vehicle in motion.

[2]. In the paper, WEEE is defined as:

a) Waste Electrical and Electronic Equipment (WEEE) from the disposal of end-of-life vehicles,

b) Waste Electrical and Electronic Equipment (WEEE) as unsorted municipal waste.

[3]. What is the most important directive regarding ELV's and WEEE in Ro?

a) GEO 5/2015 regarding electrical and electronic equipment waste

b) Directive 2002/95/EC on restrictions on the use of certain hazardous substances in electrical and electronic equipment

c) Directive 2012/19/EC on the management of WEEE.

[4]. What is the order of the five responsibilities if you produce, distribute or sell WEEE?

a) reporting, registration, taking over, organizing, restricting dangerous substances

b) registration, reporting, organization, taking over, restriction of dangerous substances

c) acquisition, registration, reporting, restriction of dangerous substances, organization

[5]. What are the measures taken by vehicle manufacturers to prevent waste?

a) Limiting and reducing as much as possible the use of hazardous substances in the construction of vehicles, starting from the design phase

b) The design and construction of new vehicles with the provision of the possibilities of disassembly, reuse and valorization of their components and materials;

c) Developing the use of recycled materials in the production of new vehicles or other products.

[6]. What are the criteria for classifying electrical and electronic devices?

a) low voltage/high voltage devices, alternating current/direct current, monopolar devices; multipolar (bipolar, tripolar).

b) long-term; permanent; intermittent; short duration

c) nominal voltage; the type of current; the number of poles; operating regime; place of operation; the functions they perform, etc.

[7]. What is WEEE??

a) various forms of EEE that no longer have value for their users;

b) various forms of EEE that no longer serve their original purpose;

c) various forms of EEE that are useful and serve the initial purpose.

[8]. What are the recycling measures?

a) dissolution of disassembly companies;

b) the development of new design technologies;

c) obtaining as few components as possible after recycling.

[9]. What are the recycling methods?

a) Delivery; Depollution; Crushing; Sorting;

b) Storage; Depollution; Crushing;

c) Shredding; Depollution; Crushing

[10]. What is the correct order of the three R's:

a) Reuse, Recycle, Reduce

b) Reduction, Reuse and Recycling

c) Recovery, Reuse and Recycling

[11]. What are the reasons why a vehicle is taken out of service?

a) Natural;

b) Premature;

c) Personal.

[12]. Which are the vehicle categories that can be included in ELV's?

a) M1 and N1

b) M1 and T1

c) M1 and N2

[13]. What are the national programs that address both natural persons and economic agents?

a) Rabla Clasic;

b) Rabla Plus;

c) E-Rabla

[14]. Which WEEE systems are part of the ELV's?

a) automotive lighting systems

b) steering systems

c) multimedia navigation systems installed on vehicles
d) braking system
e) centralized closing systems - electric windows

[15]. What the car's electrical system is made of?

a) power supplies, tires, controls and bodywork.
b) current sources, consumers, control elements and electrical wiring
c) power supplies, particle filter, oil filter and electrical wiring.

[16]. What is the common point between WEEE and ELV's?

a) secondary raw material waste
b) printed circuit board waste PCBs

[17]. What is the process by which we can recover Au and Ag with impurities of maximum 0.005%?

a) Pyrometallurgical treatment
b) Hydrometallurgical treatment
c) Electrochemical treatment

[18]. What are the best known technologies for metal separation?

a) Magnetic separators;
b) Separators with eddy currents;
c) Helicoid separators;
d) Electrostatic / electrodynamic separators.

[19]. What WEEE is composed of?

a) metal (40%), plastic (30%) and refractory oxides (30%)
b) plastic (40%), ferrous metals (30%) and non-ferrous metals (30%)
c) plastic (40%), ferrous metals (30%) and oxides (30%)

[20]. To recycle metals and get rid of other organic substances use:

a) Pyrometallurgical treatment;
b) Hydrometallurgical treatment;
c) Electrochemical treatment.

[21]. What treatment is applied especially to exidic ores?

a) Pyrometallurgical treatment;
b) Hydrometallurgical treatment;
c) Electrochemical treatment.

[22]. What are the major components of WEEE management?

a) WEEE collection, sorting and transport system,

b) WEEE treatment system,

c) WEEE final disposal system.

[23]. What are the benefits of the circular economy?

a) protecting the environment,

b) decrease in the efficiency of resource use;

c) generate opportunities for new business models;

d) generates job stagnation;

[24]. Which are the cities where the transition process to an EC from Ro was implemented?

a) Cluj, Oradea, Buzau, Iasi

b) Bucharest, Timisoara, Cluj

c) Pitesti, Oradea, Bucharest

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Module_10

End of Life
Vehicle Disposal

Valentina BĂJENARU

Recycling processes – WEEE disassembly and recycling industry

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