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Review

Recycling of Rolling Stocks

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Abstract: This review paper presents the importance of recycling, nowadays, in our society. Firstly, it demonstrates that modern rolling stocks can be useful for this environmental benefit since almost all the materials involved in their composition can be recycled and reutilised. To begin with, a brief definition and concept of each type of train are discussed herein, accompanied by some demonstrative illustrations. Then, in order to explain better the component analyses, the recovery rates and the percentage of each material belonging to trains composition have been highlighted. In this way, an idea of the quantity of the materials that can be recycled was designed. Furthermore, the suitable end-of-life rail vehicles procedures are discussed, as well as the life cycle of the main materials in which both criteria take into account the environmental issues and the best and safest way to deal with them. Finally, this research reports more specifications about the applications of all the recycling processes involving those principal railway materials. The aim of this study is to make the manufacturers and industries aware of how rolling stock recycling can bring benefits to the environments and, consequently, to the society.

Keywords: railway; trains; rolling stocks; recycling; reuse; life cycle; environmental benefit

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1. Introduction

This research study portrays the importance and significance of having a proper disposal of the end-of-life rolling stocks. Besides the social responsibility, manufacturers and owners of rolling stocks must respect and accomplish the ecological aspects involved. When producing new rolling stocks, the manufacturers must consider the whole construction process (life cycle) of a vehicle, which contains the production (building and design), operation (usage and maintenance) and, finally, what it is the main point of this research – the vehicle disposal (end-of-life). The last stage of the life cycle of a rolling stock can be considered successful if it achieves the principle of the 3R: reduce, reuse and recycle. Considering future environmental impacts, the design stage of new rail vehicles already needs to look for a reduction in the amount of waste generated after the disposal of the materials. Then, the largest amount of the generated waste must be recycled.

Since the amount of waste originated by the rolling stocks is much greater than general motor vehicles, the importance of the development of recycling becomes even higher [1]. For instance, the disposal of a single cargo railcar, in relation to the weight of the waste, is the same as 16-20 passenger vehicles. Furthermore, the disposal of a tram with an average length of 30 m results in a waste equivalent to that of 36-42 passenger vehicles and a disposal of a passenger railcar also generates a considered value of waste – 48-57 passenger vehicles. In the same way, a three-part electric multiple unit can originate as much waste as 126-156 passenger vehicles [1].

Besides those facts mentioned, the benefits obtained from the recycling of rail vehicles also have to be taken into consideration. Among those benefits, it can be stated: the reduction of the exploitation of the resources, lower costs of production of those recycled materials or even the profits of a good product image – relating the rail vehicles to the environment friendliness. Hence, an effective end-of-life rail vehicles treatment is needed due to some reasons, such as energy efficiency issues, higher raw materials costs, rigorous landfill legislation and need for landfilled waste minimization, and others environmental regulations associated with the producer's responsibilities, the increase in customers' environmental requirements, and the benefits and profits earned due to the eco-friendly products [1].

2. Methods and Materials

2.1. Components Analysis

Trains are classified according to their purposes. In Europe, the main kinds of trains are: passenger trains, high-speed rail and freight trains [2]. Each type is designed with different components and materials, as is going to be explained below:

2.1.1. Passenger Trains

A passenger train contains passenger-carrying vehicles that, usually, has a great length and speed. It can be a self-powered railcar, or a combination of one or more locomotives and one or more trailers, known as carriages, cars or coaches. The function of passenger trains is to provide a way of displacement of passengers between the stations. They operate according to fixed schedules and have a higher occupancy than freight trains. The conductor of passenger trains has the assistance of others crew members. Some passenger trains still may use bi-level cars to carry more people per train [1-2]. The following figures illustrate how passenger trains look like:

(**a**) (**b**)

Figure 1. Passenger train (**a**) External part of a passenger train [1]; (**b**) Interior of a passenger train [2].

At the end of a vehicle life, there must have a proper disposal, which means recycling – utilization of the waste for further recovery – or energy recovery – use of the energy obtained from the combustion of the waste, depending on the kinds of materials [2].

The materials, which come from rail vehicles, can be divided into seven main categories: metals; glass; fluids (lubricants, oils, chemical fluids); polymers, excluding elastomers – polymer compounds, reinforced polymers; modified organic natural materials (MONM – cotton fleece, wood, leather); elastomers (rubbers); and others, such as components that do not have an accurate material composition, for instance, electronics and electrics [2].

Trains are largely made of aluminium, steel or stainless steel – metals that are easy to recycle. The costs of steel production from materials which have been recovered are much lower compared to the iron ores production. Although aluminium does not lose its properties after recycling, the versatility of the alloys utilised to build rail vehicles makes the process more difficult [2].

However, passenger trains are more difficult to recycle, due to the multiple units in particular and to a varied material structure. In addition, there are no technologies economically efficient to recover composite materials, such as carbon fibers (Carbon Fiber Reinforced Polymer) or glass fiber reinforced polymer, as new technological solutions [2].

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The percentage data that is going to be presented in the next tables were based on drawings obtained from articles, as can be seen in the following Figures:

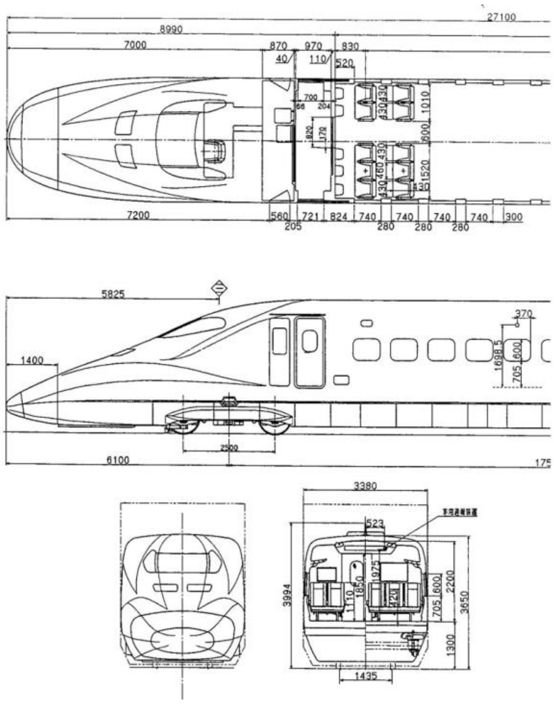

Figure 2. Major dimensions of front car of MIN350 test passenger train [3].

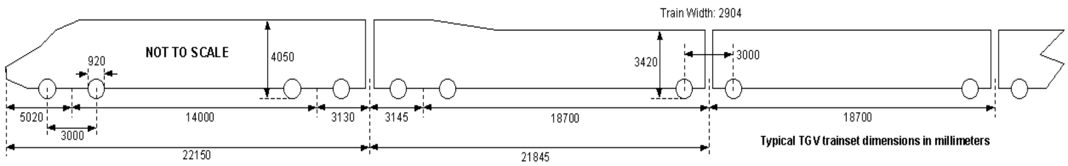

Figure 3. Key dimensions for a typical TGV trainset, in millimeters [4].

Table 1. Components Analysis of Passenger Train

PASSENGER TRAIN COMPONENTS

COMPONENTS OF TRAIN	TYPE OF MATERIAL	RECOVERY RATE	PERCENTAGE (%)
Wheels	Steel R7 (carbon content % < 0.52)	90 - 98%	0.0014
Window	Glass	50 - 100%	0.000851
Roof	Aluminium/Steel	80–95% / 90 - 98%	4.15
Table	Polypropylene, polyethylene	50–70%	1.72
Seat	Polypropylene, polyethylene	50–70%	6.78
Door	Aluminium/Steel	80–95% / 90 - 98%	0.46
Battery Box	CRCA sheet and rolled sections of carbon steel	CRCA sheet and rolled sections of carbon steel (90 - 98%)	0.000735
Pantograph	High-strength tubular steel or alloy frame; alloy of carbon, copper	High-strength tubular steel or alloy frame (90 - 98%); alloy of carbon, copper (60–80%)	0.00866
Vacuum	-	-	71.38
Carbody / tumblehome	Aluminium/Steel	80–95% / 90 - 98%	7.3538

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Brake Control Unit	Aluminium/Cast Iron/reinforced carbon–carbon	80–95% / 80–90%	0.00001286
Condenser	Copper, brass, aluminium, or stainless steel	Copper (60–80%), brass, aluminium (80–95%), or stainless steel (80%-90%)	0.000213
Compressor	Aluminium	80–95%	0.026
Coupler	Steel	90 - 98%	0.00001725
Gangway Bellows	Silicone-coated fabric	50–70%	4.33
Electrical Auxiliary Equipments			
Battery	Polypropylene, polyethylene or plastic-coated steel	50–70%	0.000735
Generator	Magnetic steel and copper	Magnetic steel (90 - 98%) and copper (60–80%)	0.00349
Alternator	Steel	90 - 98%	0.000116
Converter	Silicon Carbide	50–70%	0.002045
Bogie Components			
Bogie Frame	Steel plate/cast steel	90 - 98%	1.15
Bogie Transom	Steel plate/cast steel	90 - 98%	0.329
Brake Cylinder	Aluminium	80–95%	0.1645
Primary Suspension Coil	Steel	90 - 98%	0.329
Motor Suspension Tube	Steel	90 - 98%	0.1645
Gearbox	Steel	90 - 98%	0.1645
Motor	Steel	90 - 98%	0.4935
Secondary Suspension Air Bag	Textile-reinforced rubber	50–70%	0.4935

2.1.2. High-speed Rail

A high-speed rail belongs to a long-distance train category. They can run at speeds above 250 km/h and operate on specific and dedicated tracks prepared to support high speeds. Japan's Shinkansen is the first successful of a high-speed passenger rail system, which begun to operate in 1964. The fastest train, currently running on rails, is France's TGV (Train à Grande Vitesse – "high speed train"). In most situations, when distances do not exceed 900 or 1,000 km, high-speed rail travel is more time and cost-competitive than air travel. The use of tilting technology is common, nowadays, to improve the stability in curves. It is an artificially dynamic form of superelevation, which allows low and high speed traffic to utilise the same trackage and producing a more comfortable ride for the passengers. This technology can be found, for instance, in Advanced Passenger Train (APT) [2].

(**a**)

(**b**)

Figure 4. High-speed Rail (**a**) Japan's Shinkansen [5]; (**b**) High Speed Rail [6].

Table 2. Components Analysis of High-Speed Trains

HIGH SPEED TRAIN COMPONENTS

COMPONENTS OF TRAIN	TYPE OF MATERIAL	RECOVERY RATE	PERCENTAGE (%)
Wheels	Steel R7 (carbon content % < 0.52)	90 - 98%	0.0014
Window	Glass	50 - 100%	0.000851
Roof	Aluminium / Steel	80–95% / 90 - 98%	4.15
Seat	Polypropylene, polyethylene	50–70%	6.78
Table	Polypropylene, polyethylene	50–70%	1.72
Vacuum	-	-	71.38
Door	Aluminium / Steel	80–95% / 90 - 98%	0.46
Battery Box	CRCA sheet and rolled sections of carbon steel	CRCA sheet and rolled sections of carbon steel (90 - 98%)	0.000735
"Grand Plongeur Unique" Pantograph	High-strength tubular steel or alloy frame; alloy of carbon, copper	High-strength tubular steel or alloy frame (90 - 98%); alloy of carbon, copper (60–80%)	0.00866
Main Transformer	Steel / Aluminium	90 - 98% / 80–95%	0.0192
Thyristor controlled-rectifier bridge	Silicon Steel	90 - 98%	0.0000239
Traction Inverters	Aluminium	80–95%	0.002045
Synchronous AC traction motor	Steel	90 - 98%	0.000169
Mechanical Transmission	Aluminium alloys/steel	80–95% / 90 - 98%	0.00084
Impact absorption block	Aluminium	80–95%	0.00093
Carbody/tumblehome	Aluminium/Steel	80–95% / 90 - 98%	7.8311
Brake Control Unit	Aluminium/Cast Iron/reinforced carbon–carbon	80–95% / 80–90%	0.00001286
Condenser	Copper, brass, aluminum, or stainless steel	Copper (60–80%), brass, aluminum (80–95%), or stainless steel (80%-90%)	0.000213
Compressor	Aluminium	80–95%	0.026
Signalling Antennas	Aluminium	80–95%	0.00002

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Coupler	Steel	90 - 98%	0.00001725
Gangway Bellows	Silicone-coated fabric	50–70%	4.33
Electrical Auxiliary Equipments			
Battery	Polypropylene, polyethylene or plastic-coated steel	50–70%	0.000735
Braking rheostat/Dynamic Brake	Aluminium / steel	80–95% / 90 - 98%	0.000639
Common Block/DC circuit breaker and the main filter capacitor	Insulation sheet, bimetallic strip, silver point, ceramic RFI/EMI suppression capacitors	60- 85%	0.000939
Generator	Magnetic steel and copper	Magnetic steel (90 - 98%) and copper (60–80%)	0.00349
Alternator	Steel	90 - 98%	0.000116
Converter	Silicon Carbide	50–70%	0.002045
Bogie Components			
Bogie Frame	Steel plate / cast steel	90 - 98%	1.15
Bogie Transom	Steel plate / cast steel	90 - 98%	0.329
Brake Cylinder	Aluminium	80–95%	0.1645
Primary Suspension Coil	Steel	90 - 98%	0.329
Motor Suspension Tube	Steel	90 - 98%	0.1645
Gearbox	Steel	90 - 98%	0.1645
Motor	Steel	90 - 98%	0.4935
Secondary Suspension Air Bag	Textile-reinforced rubber	50–70%	0.4935

2.1.3 Freight Trains

A freight train is the one, which contains freight wagons or freight cars that make the transportation of materials and goods. Transporting freight by train can have more economical advantages and efficiency compared to transporting freight by road. The rail transportation is economic when freight is being carried in bulk and over long distances, however, it is less appropriate to small loads and short distances. On the other hand, the lack of flexibility is the main disadvantage of rail freight. Consequently, freight trains have been less required. Governments are trying to fortify transportation onto trains, due to the advantages that this would bring. There is a range of different types of freight trains, with many different types of cars, which are utilised according to the kinds of goods they have to carry [2]. Containers trains are one of the most conventional types of modern railways, since containers can be lifted off on the train by cranes and loaded off onto trucks and ships. "Piggy-back" trains or rolling highways are used in some countries. Trucks can also drive straight onto the train and when the final destination is reached, they drive off again. A similar system is utilised through the Channel Tunnel that interconnects England and France. Roadrailer is an alternative type of "intermodal-vehicle" designed to be attached to the train. Furthermore, there are many other types of wagon: well wagons or "low loader" wagons for the transportation of road vehicles, open-topped wagons for the transportation of minerals and bulk material, refrigerator cars for the transportation of food, and tankers for the transportation of gases and liquids. Nowadays, hopped wagons are transporting most coal and aggregates due to the facility of discharging and filling quickly [2].

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Figure 5. Freight Train [7].

Cargo railcars are the easiest to recycle, since around 60 to 80% of their mass is composed of cast iron and steel [2]. Freight trains are, basically, divided into two parts: the locomotive and the cargo railcars. The components analysis and their respective percentages of recycling are recorded in the table below:

Table 3. Components Analysis of Freight Trains

COMPONENTS OF TRAIN	TYPE OF MATERIAL	RECOVERY RATE	PERCENTAGE (%)
Diesel Engine (large cylinder block)	Cast iron / aluminium alloys	80–90% / 80 -95%	0.045
Main Alternator	Steel	90 - 98%	0.000116
Auxiliary Alternator	Steel	90 - 98%	0.000083
Motor Blower	Cast iron / aluminium alloys /Steel	80–90% / 80 -95% / 90 - 98%	0.00017
Air Intakes	Steel/Aluminium	90 - 98% / 80 -95%	0.0000364
Rectifiers/Inverters	Heavy-gauge aluminium sheet metals with powder-coated or anodized and stainless fittings	80 -95%	0.002045
Battery	Polypropylene, polyethylene or plastic-coated steel	50–70%	0.000735
Traction Motor	Steel	90 - 98%	0.4935
Pinion/Gear	Steel	90 - 98%	0.0000546
Fuel Tank	Steel / Aluminium	90 - 98% / 80 -95%	0.000479
Air Reservoirs	Steel / Aluminium	90 - 98% / 80 -95%	0.0000441
Air Compressor	Aluminium	80 -95%	0.026
Drive Shaft	Aluminium alloys	80 -95%	0.0019
Gearbox	Steel	90 - 98%	0.1645
Radiator and Radiator Fan	Aluminium,brass or copper cores	Aluminium (80 - 95%), brass or copper cores (60 - 80%)	0.000232
Turbo Charging	Cast Aluminium	80 -95%	0.0000383
Truck Frame or Bogie Frame	Steel plate / cast steel	90 - 98%	1.15
Wheels	Steel R7 (carbon content % < 0.52)	90 - 98%	0.0014

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Roof	Steel	90 - 98%	4.15
Vacuum	-	-	79.87
Door	Aluminium / Steel	80–95% / 90 - 98%	0.037
Carbody / tumblehome	Steel	90 - 98%	13.89106
Sand Box	Cast iron	80–90%	0.000173
Battery Box	CRCA sheet and rolled sections of carbon steel	CRCA sheet and rolled sections of carbon steel (90 - 98%)	0.000735
Brake Control Unit	Aluminium / Cast Iron / reinforced carbon–carbon	80–95% / 80–90%	0.00001286
Brake Cylinder	Aluminium	80–95%	0.1645
Condenser	Copper, brass, aluminium, or stainless steel	Copper (60–80%), brass, aluminium (80–95%), or stainless steel (80%-90%)	0.000213

3. Results

3.1 End-of-life Rail Vehicles Procedure

The disposal of rail vehicles can be compared to the process of disposal of motor vehicles. The disposal process is divided into five stages [1-2]:

1. Forwarding the rolling stock for recycling:

The first decision that has to be made is the decommissioning of a vehicle and the place where dismantling will be environmentally safe and the recovery rate will be high. In general, rail vehicles have a life cycle of approximately 30-40 years. The decommissioning decision considers the rolling stock damage, the high costs of repairs, malfunctions, and high maintenance costs if compared to new models available on the market [1-2].

2. Pre-treatment:

End-of-life rolling stock is treated as hazardous disposal [1]. Therefore, the waste must guarantee safety for human health and the environment at all the stages of the recycling process. In this way, the initial treatment involves the removal of pollutants and hazardous waste. Operating fluids, such as brake fluids, oils and antifreeze, which are removed from the vehicles must be stored in containers separated from the others in order to be forwarded to specialized facilities responsible for energy recovery (oils) and material recycling. Some components that are going to be reused as spares are not drained. Gases, fire extinguishers, greases, explosives, braking sand, batteries and catalytic capacitor have to be removed, due to environment hazards and health. As the operating fluids, they are forwarded to specialized recycling facilities [1-2].

3. Dismantling

Parts that can be further recycled, in the dismantling process, are removed. First of all, subcomponents and parts that are going to be reused are retrieved, such as, wheel sets, bogies, bogie frames, buffers, springs, couplings, doors, brake systems and control valves. Some of them can be used, directly, in other rail vehicles, while others will need refurbishment to regain the original operating parameters. Those parts that are going to be reused must have a special care when being removed to avoid damage and must pass through an inspection so that to determine the possible admittance for use and the extent of refurbishment if needed. The rest of the elements, such as glazing, seats, wire harnesses, flooring and electronic parts are, then, dismantled for further material recycling. The greater the extent of the dismantling, the easier it is the separation of individual

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material fractions and the more effective becomes the recycling process. In this way, the highest possible number of elements should be dismantled at this stage, however, since it is a costly process, its extent must be economically justified. Moreover, the dismantling process should also take into consideration the energy saving so that to enhance its effectiveness. Therefore, the manufacturers must look at the quality of the materials and classify by themselves the materials that really would bring future environmental and economical benefits. Then, the subcomponents and elements removed during this process are forwarded to specialized recycling facilities, where they are sorted, separated and undergo an appropriate recycling process [1-2-3].

4. Shredding

After the dismantling of the elements for material recycling, the vehicle goes to the industrial shredder for scrapping. There are three ways to shred: shearing, tearing and fracturing. All the three actions are present while a shredder is being used, however, focusing on energy saving as in the dismantling process, shearing would be the most efficient reduction action to be considered. Before going to the shredder, the waste is pressed to reduce the space needed for the transportation, which decreases the cost of the freight. Then, the packed materials are grinded into small pieces for further treatment. The aim of the industrial shredder is the recovery of the metal fractions. Consequently, the waste is segregated in ferrous metals (steel and irons), non-ferrous metals (aluminium, zinc, copper, magnesium) and light shredder residue (a moisture of different substances and materials, for instance, fibers (textiles, wood), plastics (including foam and textiles), elastomers, glass and ceramics, residue (dust, paint coatings, rust) and remaining minerals (soil, sand). Ferrous and non-ferrous metals receive treatment to become recycled materials. Light shredder residue must be segregated for reuse or partly combusted for energy recovery, since it has a high calorific value. Around 50% of the light shredder residue contains a combustible portion that can be thermally treated. Although there are new technologies that enable sorting and using up to two-thirds of the mass of the shredder residue, in practice, approximately 67% of the remains, after the shredding process, is landfilled [1-2-4].

5. Treatment of recovered materials

All the components and elements dismantled, except those which are good for direct reuse, are forwarded to specialized recycling facilities. Batteries, elements containing hazardous substances, operating fluids, electronics, parts for refurbishment, plastic and electric elements must receive dedicated recycling. In the same way, the materials segregated in the shredding process are forwarded to steelworks or non-ferrous metal recycling facilities. Some separated fractions of the shredder residue can be directly used in the industry, for example, fibers and foams can be utilised in sewage sludge conditioning and polymer granulate can be used in a blast furnace [1-2].

3.2 Life cycle of the materials

- Steel

A life cycle assessment (LCA) of a steel product looks at energy, resources and emission, from the steel production stage to its end-of-life stage, including recycling. Without any loss of its inherent properties, steel can be recycled over and over again. The steel industry has many competitive advantages over competing materials in a circular economy, due to four keywords: reduce (over the past 50 years, steelmakers have, significantly, reduced the amount of energy required and raw materials to make steel. Furthermore, through investments in research and technology, the steel industry is developing the use of high-strength and advanced high-strength steel grades in many applications, in which less steel is needed to provide the same strength and functionality), reuse (due to its durability, steel can be reused with or without remanufacturing), remanufacture (many steel products can be remanufactured for reuse) and recycle (steel is 100% recyclable to create new steel products). The image 6 above illustrates the life-cycle of steel [5].

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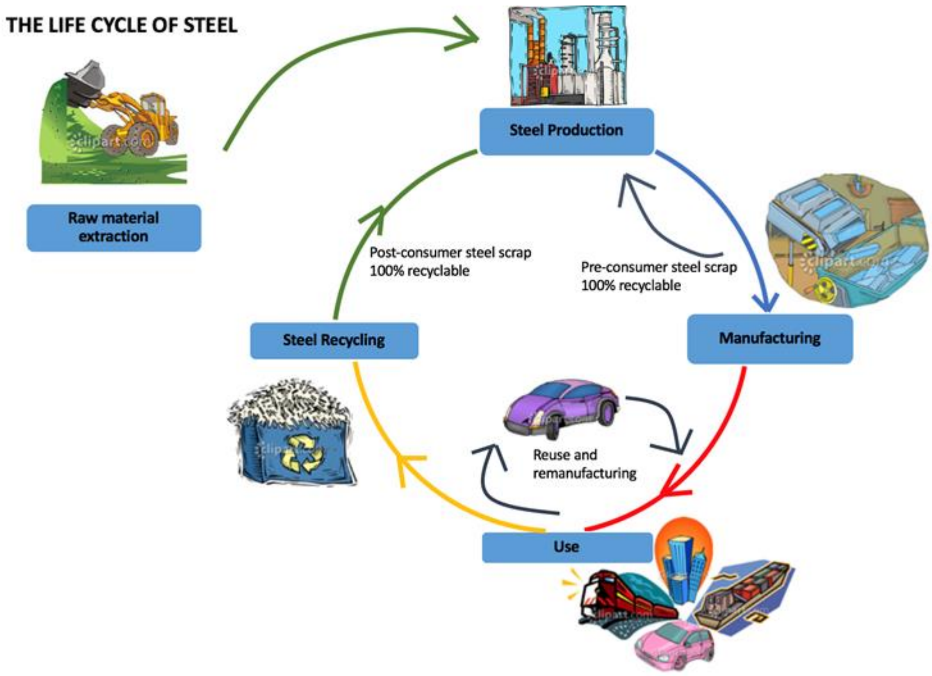

Figure 6. Life cycle of steel [adopted from 8].

- Aluminium

The aluminium industry covers three activities: initial processing and ore extraction, transformation into semi-products and, to finish off, the lifecycle of the finished goods, which can be fully recycled. Approximately 75% of all the aluminium ever made is still in productive use. Almost 100% of aluminium is infinitely recyclable [6].

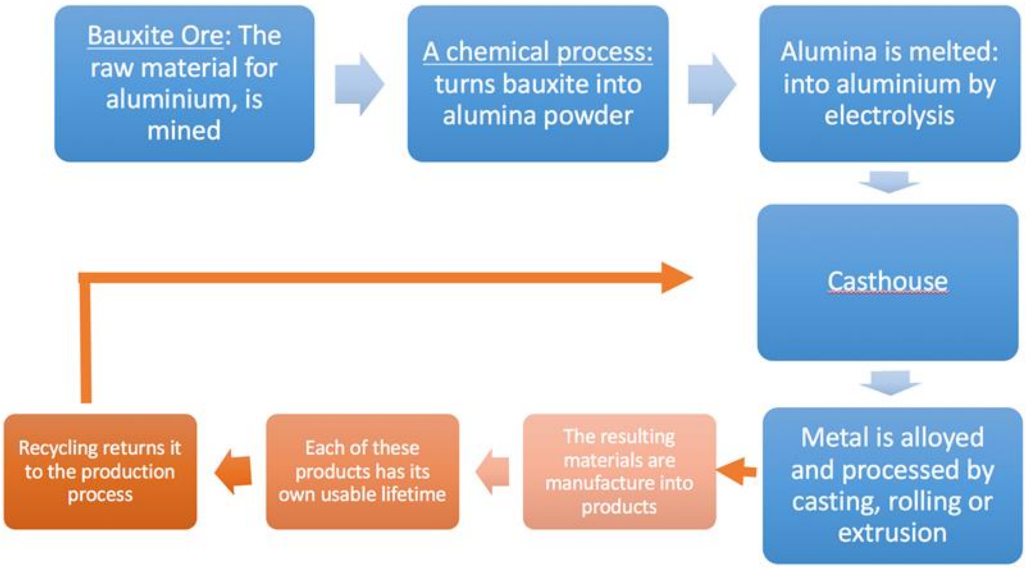

Figure 7. Life cycle of aluminium [adopted from 9].

- Plastic

Although some plastics may be biodegradable or compostable, evidence indicates that this feature does not reduce waste. Compostable plastics do not degrade in landfills either. Composting and biodegradation release carbon dioxide (CO_2) into the atmosphere. The primary environmental impacts associated with plastic manufacturing are the Global Warming Potential, due to CO_2

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emissions from raw materials and Primary Energy Demand, for which the main contribution is the upstream production of energy, specifically, natural gas [7].

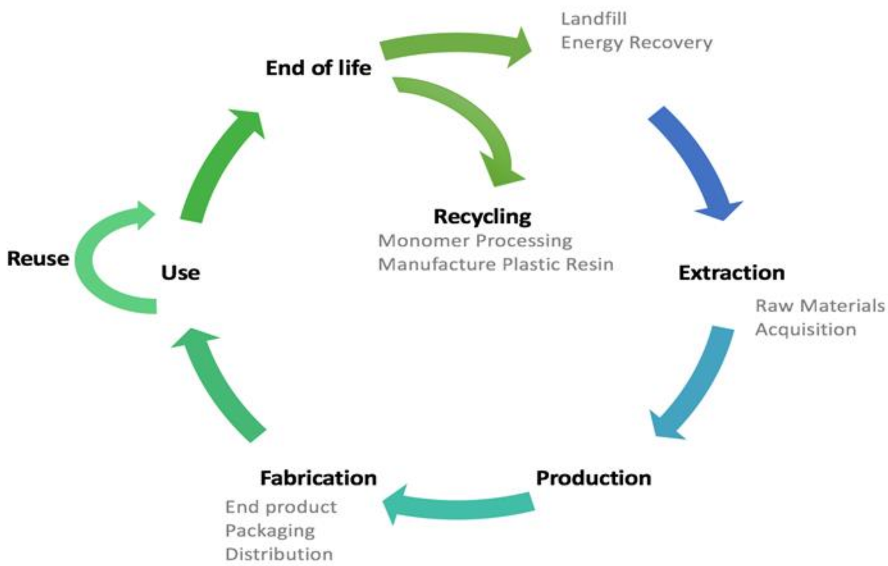

Figure 8. Life cycle of plastic [adopted from 10].

- Glass

Transportation of cullet and raw materials used in glass production represents less than 10 percent of the total energy utilised in the production of glass. The CO_2 savings from glass recycling are larger than the transportation emissions [7].

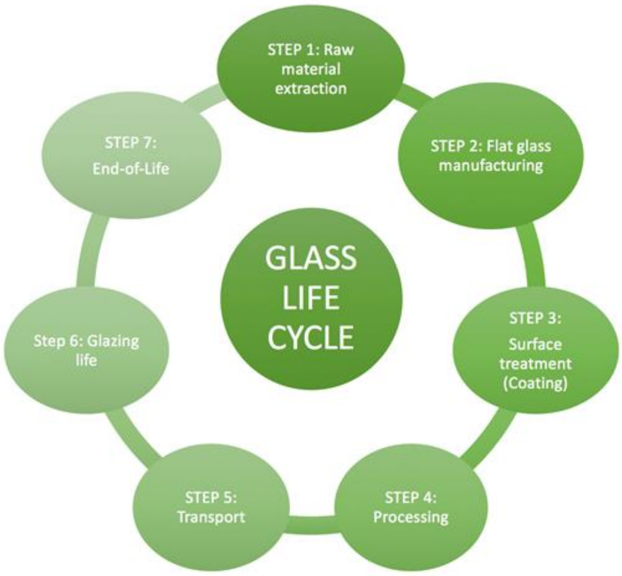

Figure 9. Life cycle of glass [adopted from 11].

3.3 Applications of the rolling stocks' recycling

As it has been recorded in the tables above, some rail materials present a high recovery rate, which can be recycled and used in different applications. Reusing metal implies in reduction on emissions of CO_2. One tonne of reused metal displaces one tonne of new metal [8]. Reuse only has emissions implications at the time of construction or manufacture. In this section, it will be reported the applications of the main materials recycled from the trains:

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- Steel

Steel is considered a recoverable material since it is easy to make the magnetic separation. Among the materials studied in this report, steel is the one with the highest recovery rate, between 90-98%. The steel production from recoverable material has low costs compared to the iron ores' production. It is an essential material for rails. For instance, 20-25% of the mass of passenger and high-speed trains are composed of steel. The bogies (the structure underneath the trains, such as wheels, bearings, axels and motors) are the main steel components. Freight trains are made totally of steel. It is also present in the rail track sleepers and fasteners, bridges, stations and overhead power lines (catenary poles). Its durability enables rails to be reused by swapping over the left and the right on the track. When no more suitable for main-line use, rails can be tested for crack and then reutilised on secondary lines with smaller traffic. Recycling the steel track at the end of its life results in a significant reduction in the energy cost associated with the material and the environmental impact. After track components and rails achieve the end of their life (around 30 years), almost all the steel will be recovered [8-9-10-11].

- Aluminium

Currently, more than a half of all aluminium produced in the European Union is originated from recycled raw materials. As steel, aluminium can be recycled without loss of its properties. Recycling aluminium conserves energy and other natural resources. It saves more than 95% of the energy required for primary aluminium production, avoiding, then, emissions of greenhouse gases. Recycled aluminium can be used in several applications, such as computers, automobiles, siding, gutters, wire, boats, bicycles, cookware and many other products which need a strong lightweight material, or a material with a high thermal conductivity. Global aluminium recycling rates are high, 60% for beverage cans and, approximately, 90% for construction applications and transport (in the majority, rails). In this way, all the train components made of aluminium can be reused after specific treatments. Furthermore, it is an economical process, since it uses less energy and recycling is self-supported, due to the high value of used aluminium [6-12].

- Plastic

Recycling helps saving resources, its value lies in the reduction of greenhouse gas emissions, as well as the minimization of waste going to landfills. Terminology for plastic recycling is complex since there is a wide range of recovery activities and recycling. There are four categories: primary (mechanical reprocessing into a product with equivalent properties, often referred to as "closed-loop recycling"), secondary (mechanical reprocessing into products that require lower properties, "downgrading"), tertiary (recovery of chemical constituents, applies when the polymer is de-polymerized to its chemical constituents, "chemical" or "feedstock recycling") and quaternary (recovery of energy, from waste or valorisation) [8]. Closed-loop recycling is most used when the polymer constituent can be, effectively, separated from sources of contamination or stabilized against deterioration during reprocessing and future reuse. In some cases, recovered plastic that is not adequate for recycling into the prior application is used to make a new plastic product displacing all, or a proportion of virgin polymer resin – primary recycling. Some examples are plastic bins and crates manufactured from HDPE of milk bottles, and PET fibre from recovered PET packing. Secondary recycling happens when recovered plastic is put into an application that would not use virgin polymer, for example, "plastic lumber" (used in the trains, for instance, in the tables) as a solution to the high cost and small lifetime of timber. In tertiary recycling, there is the advantage of recovering the petrochemical constituents of the polymer, which can be used to make other synthetic chemicals or to re-manufacture plastic. Chemical recycling of PET is considered more successful since de-polymerization under delicate conditions is possible. Glycolysis, hydrolysis or methanolysis, for example, can break down PET resin to make unsaturated polyester resins [7-13].

- Glass

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Recycling glass provides for unmatched production efficiencies and considerable environmental benefits: lessens the demand for energy, cuts CO_2 emissions, decreases the number of raw materials used, extends furnace life without any processing by-products and saves on overall manufacturing costs. Therefore, it is essential to recycle the glasses used in the trains, so that to save money and the environment [7]. Moreover, recycled glass is being used, nowadays, as aggregate in concrete. Due to its better thermal properties of the glass aggregates, concrete made with recycled glass aggregates have shown better thermal insulation and better long-term strength. One ordinary application is as pipe bedding – located around sewer or water pipes to transfer weight from the surface and to protect the pipe. Other uses for recycled glass include: ceramic sanitary ware production, fiberglass insulation products, recycled glass countertops, abrasives, and agriculture and landscape applications, such as top dressing, root zone material or golf bunker sand [14].

Currently, there is a group of manufacturers offering vehicles that are fully adapted to the needs of rolling stock recovery and recycling. For instance, Bombardier Transportation adopted a resolution that all manufactured vehicles will aim at a 100% recovery rate. This will be possible with the minimization of use of hazardous materials and substances, as well as the application of recycling-friendly materials, such as aluminium and steel, and the avoidance of an excess number of materials [15].

4. Discussion

As it has been reported above, there are many possible applications for the materials recycled from the rolling stocks. During all the recycling process, the manufacturers must consider the costs needed and the quality from each material, in order to achieve the best efficiency and cost-benefit. In the same way, energy requirements, carbon emissions and environmental impacts also have to be analysed in the whole process. Firstly, steel – the recycling process helps to save landfill space while providing a valuable scrap resource to the steel industry. Using recycled steel to make new products preserves energy and natural resources. For instance, for every ton of steel recycled, 1,400 pounds of coal, 2,500 pounds of iron ore and 120 pounds of limestone are conserved. Furthermore, the steel industry preserves correspondent energy to power around 18 million homes for 12 months [16]. Aluminium – the recycling process produces cost savings over the production of new aluminium and also conserves energy and natural resources. Recycling aluminium produces around 5% of the energy required to create aluminium from bauxite [17]. It also reduces the uses of natural resources and chemicals (aluminum fluoride, caustic soda and lime) and eliminates the necessity for bauxite ore to be mined. In addition, it produces 95% fewer greenhouse gas emissions (GHG) than manufacturing primary aluminium. For example, that is a GHG saving equivalent to taking 900,000 cars off the road during 12 months. 1 tonne of aluminium recycled avoids the emissions of around 9 tonnes of CO_2 emissions [18]. Plastic – the recycling of this material results in a reduction of oil consumption, since manufacturers make plastics from crude oil derivatives or natural gas: 1 ton of recycled plastic saves 16.3 barrels of oil [19]. Therefore, it helps to save the remaining fossil fuel reserves. Moreover, 1 ton of recycled plastic saves the equivalent of 5,774 kilowatt-hours of electric energy. It also reduces the amount of waste: 1 ton of recycled plastic saves around 7 yards of landfill space [20]. Then, to finish off, glass – the recycling process also brings several significant environmental benefits. It saves raw materials: for every 1 ton of recycled glass, over a ton of natural resources are conserved, such as 410 pounds of soda ash, 1,300 pounds of sand, 160 pounds of feldspar and 380 pounds of limestone [21]. As already stated, recycling glass lessens the demand for energy and cuts CO_2 emissions: for every 6 tons of recycled glass used, a ton of carbon dioxide is reduced. Furthermore, since glass recycling is a closed-loop system, it does not create additional waste [21].

5. Conclusions

Despite the fact that there is no legislation in the area of rail vehicle recycling, the European policy on waste management should be supported by rolling stocks manufacturers and its users. Since there is a lack of legislation for the rolling stock, there are no limitations to the scope of application of the individual types of disposal (energy recovery, recycling). Due to the creation of a voluntary policy, modern vehicles are prepared for their end-of-life recycling. In this way, a wide range of materials can be re-processed and then secondary raw materials can be re-used. When designing a vehicle, rolling stock manufacturers show their necessity of recycling, which can be seen through the application of recyclable materials, proper material combinations, and material marking. This occurs in order to have a quicker dismantling and separation of the materials fractions. The rolling stock recovery rate can reach up to 95%, which is similar to motor vehicles. The actual recovery rate will depend on many factors, such as: accessibility to recovery technologies, demand for recycled materials and refurbished parts, new types of materials. Moreover, expectations and environment protection policies applied by the rolling stock owners and users, legal regulations to force business entities to achieve required recovery rates and existence of infrastructure of specialized material recycling facilities.

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