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Topical Group: Life Cycle Assessment

Recyclability and Recoverability Calculation Method Railway Rolling Stock

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Foreword

UNIFE is the Association of the European Rail Industry located in Brussels. UNIFE's role is to represent its members' interests at the level of both European and international institutions and the mission of the association is to pro-actively develop an environment in which UNIFE members can provide competitive railway systems for increased rail traffic.

The UNIFE Organization is structured in several Committees. One of these Committees is the Sustainable Transport Committee (STC).

The UNIFE STC acts as a coordinator for the environmental related topics and provides a platform for consensus-building to formulate common positions. It assures a coherent and effective common position and effort of the rail industry within various environmental areas, e.g. energy efficiency, eco-procurement, control of hazardous substances, recyclability, exhaust gas emission etc.

The end of life treatment of products and reduction of waste in general are key priorities on the environmental agenda within the European Union. The railway industry need a common approach to ensure efficient recycling of the rolling stock and equipment as well as a common basis for calculating and reporting the Recyclability and Recoverability Rates for rail products. In 2009 the UNIFE STC therefore launched an expert team to develop a common recyclability and recoverability calculation method for the specific needs of the railway industry.

This purpose of this document is to present the work of that team.

The UNIFE Life Cycle Assessment topical group consists of representatives from: Alstom Transport, AnsaldoBreda, Bombardier Transportation, CAF, Knorr-Bremse, SAFT Batteries, Siemens and Talgo.

Tecnalia provided technical support during the preparation of this document.

This calculation method is an UNIFE document designed to be applied within the rolling stock manufacturing industry.

Avenue Louise 221 | B-1050 Brussels | Belgium
www.unife.org

1 Introduction

This document aims to define a common approach for the calculation of Recyclability and Recoverability Rates. Furthermore the document presents a common rail industry method in order to make recyclability and recoverability figures comparable and transparent within the railway industry. It is not the purpose of this document to recommend minimum values for recyclability and recoverability.

The calculation method is based on ISO 22628 [1], however it has been developed further in order to take into account the efficiency of recycling and recovery technologies of various materials at different stages of the recycling process and to better include the particularities of the rolling stock.

The approach of the document is practical and based on automotive recycling processes. Starting with the description and definition of recycling terms used by the recycling industry in general, the method follows the railway specific requirements of necessary material information. The method of calculation is partly covered by ISO 22628. However, pre-treatment and dismantling calculations are adapted and consider recycling and recovery properties of the materials specific to these stages. At each stage individual material flows are split into materials for recycling and materials for recovery, depending on the availability of appropriate technology for recycling and/or recovery. Therefore knowledge of materials and dismantling of rolling stock or equipment is essential. The entire supplier industry needs to be involved because material information is crucial when applying the calculation method. The harmonized calculation method for recycling characteristics of rolling stock shall prevent misleading data gaps and contradictions.

It is recommended that companies start calculating their Recyclability and Recoverability Rates with the method proposed in this document. The method shall be applied for new designs but can optionally be used for existing designs if data on materials is available.

2 Terms and definitions

Component:
A component consists of several assembled parts fulfilling a specific function.

Disposal:
Disposal covers the final placement of wastes under proper process and authority with (unlike in storage) no intention to retrieve. It means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Disposal may be accomplished by e.g. deposit into or on to land, incineration, deep injection, permanent storage.

Energy recovery:
A process of generating energy depending on the heating value, the efficiency factor and on the use of the obtained energy.

Incineration:
Combustion process without distribution of the energy potential related to incinerated substances and with high focus on reducing the volume of waste.

Material:
The substance or substances of which an object is made or composed. Composite materials made from more constituent materials will be also considered.

Part:
Smallest unit of a component which can be dismantled.

Treatment of material flows:
Recovery or disposal operations, including preparation prior to recovery or disposal.

3 Scope

3.1 General

This calculation method shall cover only the end of life stage of rolling stock or equipment, see Figure 1. The calculation shall be carried out for rolling stock or equipment as delivered. Spare parts and maintenance parts necessary to keep the vehicle in service over the entire life cycle, e.g. brake pads, are not taken into account. Also infrastructure systems like stations, electrification, signal and control units, etc. will not be covered by the calculation method.

This calculation method can be applied for all types of rolling stock or equipment according to PCR 2009:05 [5].

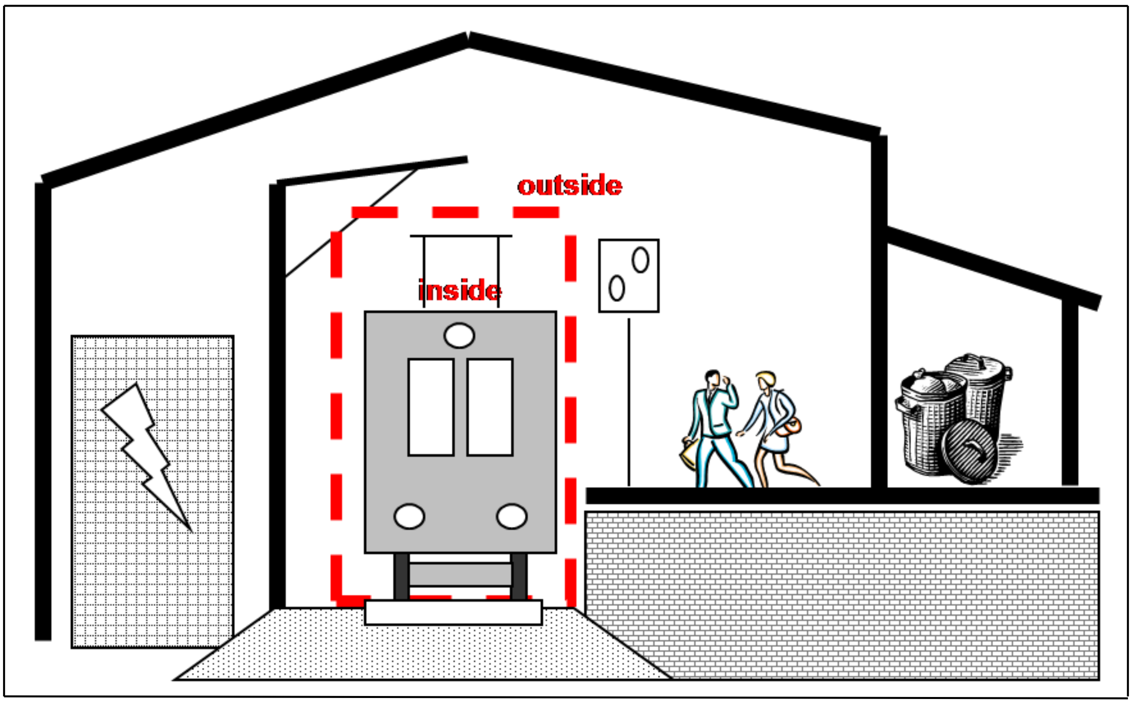

Figure 1: Scope of systems included, shown in red frame

3.2 Technical Scope

The recycling technologies are based on the four main treatment processes, which are reuse, recycling, energy recovery and disposal, see Figure 2. Process losses of recycling will be treated in the disposal stage. The residue substances of the energy recovery stage (mostly ash and slag) and the residue of the incineration process of the disposal stage will be landfilled because of European waste regulations [4].

All materials must be allocated to defined material categories according to Annex A.

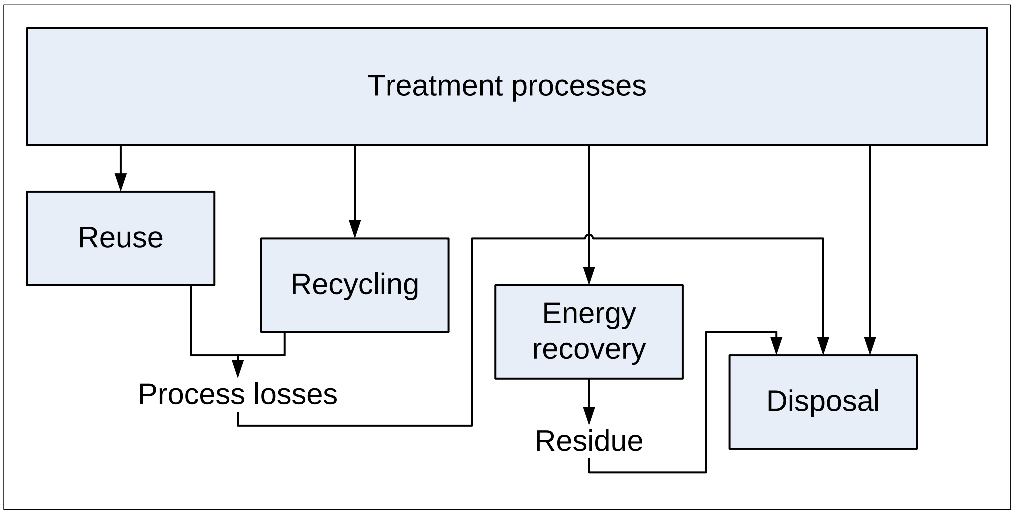

Figure 2: **End of life treatment of rolling stock**

3.3 Chronological Scope

The scope of this technical document is not limited by the year of manufacture of the rolling stock or equipment.

The calculated Recyclability and Recoverability Rates are valid at the point of delivering the first piece of rolling stock or equipment.

Calculated figures can also be applied for other life cycle stages (e.g. manufacturing).

All given data will be valid only for unmodified rolling stock or equipment. The method is based on available information about recycling technologies and standards of 2011. Future recycling technologies or predicted trends related to the recycling industry are not included in the method.

3.4 Geographical Scope

There is no geographical limitation to the application of the method. However, the proposed efficiency factors are based upon available technologies within the European Union.

4 End of Life Treatment

When rolling stock reaches its end of life it should be treated to recover as much as possible of its constituent materials and to minimize the overall environmental impact of this life cycle phase. A strategy for end of life treatment is presented in the following chapter. This strategy encourages components of the vehicle to be reused, recycled or recovered as energy as much as possible. Material that is not recovered will be considered as residue to be disposed, i.e. landfilled or incinerated.

According to previous categorization, the Recyclability Rate is determined by the percentage of mass of the vehicle that can be reused or recycled. The Recoverability Rate is defined in clause 3.8 of ISO22628:2002.

Reused products / components / parts shall be included in the recycling calculation sheet.

4.1 Description of the End of Life treatment process

The holistic recycling process (defined in Figure 1 in the ISO 22628:2002) involves three relevant steps or stages of treatment during the processing of end of life of rolling stock at common recycling plants. The process starts with the pre-treatment step followed by dismantling, shredding and metals separation and ends with the treatment of the non-metallic residues, also called Shredder Light Fraction (SLF)[1], see Figure 3. In all steps different policies and requirements should be considered to ensure no damages to humans and environment. Due to different sorting and shredding technologies, wide variations of efficiencies may occur. Following the different recycling steps generates different amounts of materials which must be considered by the calculation of the Recoverability and Recyclability Rates.

[1] Note that in the following the description and calculation of the SLF fraction are included in the chapters on shredding.

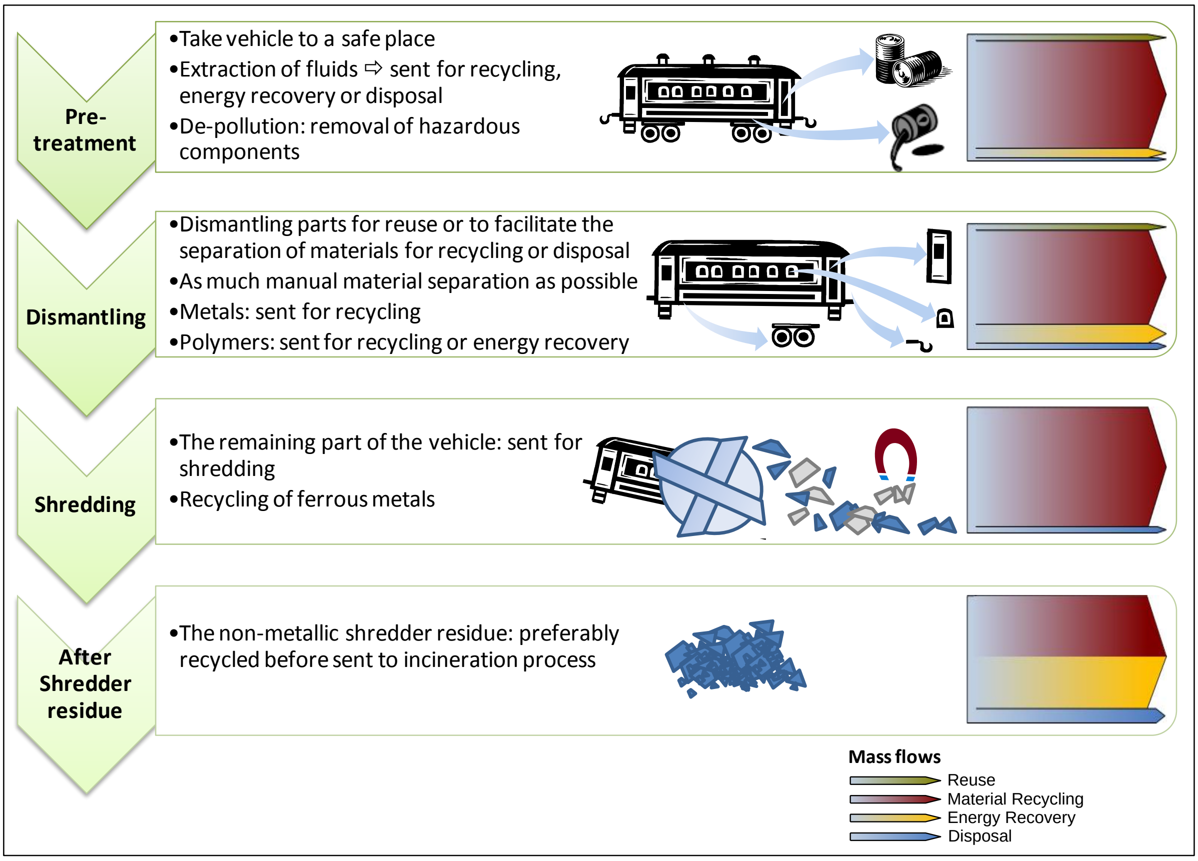

Figure 3: Steps of the Recycling process during end of life procedure of rolling stock / equipment

4.1.1 Pre-treatment m_p

Pre-treatment is the first step in a row of process stages. The aim of pre-treatment is to extract toxic and explosive substances / gases which can be harmful to human and environment.

The rolling stock or equipment must be taken to a safe place which is suitable to extract fluids and gases from the product. Step one is the drainage and removal of all kinds of fluids. The average rolling stock contains a wide variety of operating fluids, including brake fluid, antifreeze, gear oil, etc. All fluids need to be drained and disposed of carefully to avoid accidents during dismantling and the contamination of the environment during disposal. The majority of extracted substances, materials and components have to be transferred to dedicated recycling processes.

Pre-treatment is applicable for parts and fluids defined in Table 6 of Annex B.

Materials, substances and parts like oil, fluids, batteries, sand fire extinguishers and catalytic capacitors are examples of components recommended to be handled in the pre-treatment stage according to applicable legislation and specific operational safety and environmental procedures.

All fluids, components and parts which are treated in this step shall be considered in the calculation method as pre-treated mass (m_P).

There are also components which are intended for reuse.

4.1.2 Dismantling m_D

At the dismantling stage parts and components are individually removed from the vehicle structure and sub-assemblies. During dismantling parts and materials are separated and sorted for appropriate and dedicated recycling processes. Therefore the availability of special recycling processes for the dismantled sub-products, parts and components is a precondition for efficient dismantling.

The objective of the dismantling stage is to extract as much material as possible from rolling stock before entering it into the shredding process. The efficiency of the subsequent recycling processes is higher for separated materials than for those within the shredding residue. This is taken into account in the calculation algorithms via the Material Recyclability Factor, MRF, and the Energy Recovery Factor, ERF, see chapter 5. These are the factors taking into account the efficiency of the recycling process for a particular material, MRF, and the efficiency of the energy recovery process of a particular material, ERF. MRF and ERF are, in general, higher for materials extracted at the dismantling stage than for those in the shredding residue.

Before selected for dismantling the components must be checked against the requirements of the qualification list, see Annex B. Further treatment of non-qualified components will be done at the shredder stage.

Parts and components like windows, seats, floors, cables and electronic parts, HVAC units are typically examples which shall be considered at dismantling stage before shredder process.

Electronic parts should be handled as electronic and electrical scrap with specific treatment processes and sorting technologies.

4.1.3 Shredding and post-shredding process m_S

After the pre-treatment and dismantling stages, the remaining parts and materials enter the shredding process. The intention of the shredding process is to reduce the volume of the remaining part of the rolling stock and to prepare the separation of specific materials. The reduction of volume will be realized by a mechanical press. Following this the packed materials will be milled into small pieces for further processing.

After the shredding the small pieces are sorted into two different material fractions by e.g. using magnetic properties and eddy current separators. These material fractions are:

- Shredder Heavy Fraction (SHF) comprising
    - Ferrous metal fraction or ferrous fraction
    - Non-ferrous metal fraction or non-ferrous fraction

- and Shredder Light Fraction (SLF)

Material considered for the shredding process cannot be classified as reusable.

4.1.3.1 Ferrous Fraction m_{SHF1}

The Shredder Heavy Fraction 1 (SHF1) is composed of pure ferrous materials like steel and iron and its alloys. These materials are selected and recyclable.

4.1.3.2 Non-ferrous fraction m_{SHF2}

The Shredder Heavy Fraction 2 (SHF2) is composed of non-ferromagnetic materials. Specific sorting technologies can sort different materials like Aluminium, Copper, Brass, etc. with high efficiency.

4.1.3.3 Shredder Light Fraction mSLF

Non-metallic residues form what is known as Shredder Light Fraction. SLF is mostly composed of plastics, rubber, foam, residual metal pieces, paper, fabric, glass, sand and dirt.

The industry offers different processes which are able to fractionate the defined grit sizes into smaller groups that allow sending the groups into further recycling processes.

4.2 Efficiency of Recycling Processes

The suitability for recycling or energy recovery of the materials used for rolling stock and equipment is of important consideration when calculating the potential Recyclability and Recoverability Rates. Such suitability to be recycled or recovered is considered through the Material Recovery Factor (MRF) and the Energy Recovery Factor (ERF).Those materials presenting a better suitability for the recycling or energy recovery will improve the overall Recyclability Rate or Recoverability Rate of rolling stock and equipment.

The potential Recyclability Rate is defined in clause 3.10 of ISO22628:2002. Further than that, in practice the recyclability or recoverability of the rolling stock may depend on the following factors:

- Politics (law and regulations)
- Rolling stock owner (strategy, environmental guideline)
- Market (end users requirements, trends, fashion)
- Material (ability to be identified, suitability for recycling, recycling compatibility in material compounds, environmentally critical contents which have to be treated)
- Ability for dismantling (visual perceptibility, accessibility, connection/bond, dismantling time)
- Recycling technologies (availability of economically optimized recycling processes for specific target fractions)
- Raw material consumption

- Emissions (solid, liquid, gaseous)
- Cumulative consumption of energy

These factors must be considered by the manufacturer of the rolling stock and equipment for their recycling strategy. The decisions on which components will be extracted at the pre-treatment and dismantling steps influence the product Recyclability and Recoverability Rates. This calculation method gives qualification criteria, see Annex B, to help the manufacturers to make those decisions. The qualification is based on specific criteria such as joining technology, accessibility, toxicity, dismantling time, economical feasibility and environmental impact.

Furthermore the manufacturers are encouraged to study the technical and economical feasibility as well as the environmental evaluation of their recycling strategy in order to determine when dismantling is the best option. It is also up to the rolling stock manufacturer to specify the identification of the parts. Material marking allows the identification and facilitates the sorting of the materials into material categories at the dismantling phase. Those manufacturers identifying the parts will be able to allocate more components into the dismantling stage, therefore improving the product Recyclability and Recoverability Rates.

It is important to consider that the MRF and ERF are in general higher for the materials extracted at the dismantling stage than for the same materials obtained from the shredding residue. For the time being it is more efficient and economical to process the dismantled parts than the shredder residue, thus processes for recycling and energy recovery have a higher efficiency for components dismantled before the shredding phase. However, in the last years some processes have been developed for the recycling of polymers, residual metals, organic fraction and ceramic from shredder residue.

> Note: The efficiency factors of the technologies used in the document are the best available at the time of writing. Economical aspects are not taken into account in the calculation method as they depend on the conditions of each particular product. However, this document gives a list of criteria, see Annex B, to help the user in the selection of the material in the different phases of the recycling process.

4.3 Applying the Material Recovery Factor and Energy Recovery Factor to the Calculations

4.3.1 Material Recovery Factor

The MRF describes the suitability of a material to be recycled. These factors are not taken into account in the ISO22628:2002. If excluding all non-technical aspects the main criteria to determine the MRF are:

- Availability of recycling processes for the material in question
- Inefficiencies of the recycling process

The mass of each material identified for recycling in the treatment processes (as described in chapter 4.1) are multiplied by the Material Recovery Factor corresponding to the respective material type and treatment stage.

This is shown by the following formula:

$$m_{i\,(cyc)} = m_{i(treat)} * MRF_i$$

i	= material type
m	= mass
$m_{i(treat)}$	= mass of material type to be treated
$m_{i\,(cyc)}$	= result of recycling process (equation 1)

This formula is then applied to each material type for each recycling treatment process. The total of the resulting masses is added to the identified reusable material mass which is then used in the recyclability rate calculation.

The values for MRF are given in Annexes A2 to A4.

4.3.2 Energy Recovery Factor

The ERF is the suitability of a material to be recovered as energy. If excluding all non-technical aspects the main criteria to determine the ERF are:

- Availability of energy recovery processes for the material in question
- Calorific Value of the material (MJ/Kg)

The mass of each material identified for energy recovery in the treatment processes (as described in chapter 4.1) are multiplied by the Material Recovery Factor corresponding to the respective material type and treatment stage.

This is shown by the following formula:

$$m_{i(\mathrm{cov})} = m_{i(treat)} * ERF_i$$

i	= material type
m	= mass
$m_{i(treat)}$	= mass of material type to be treated
$m_{i(\mathrm{cov})}$	= result of energy recovery process

This formula is then applied to each material type for each recycling treatment process. The total of the resulting masses is added to the total recyclable and reusable material masses which is then used in the recoverability rate calculation.

The values for ERF are given in Annexes A2 to A4.

Values for MRF and ERF shall always take into account the state-of-the-art of recycling technology and therefore the values in Annexes A2 to A4 will be reviewed and updated in future revisions of this document in order to incorporate the development of the recycling technologies and materials. The implementation degree of the available recycling and recovering processes in the different countries as well as the accessibility and distance of the facilities for recycling and recovering to the dismantling and shredding locations is not considered.

5 Application of Recycling Calculation Method

The Recyclability and Recoverability Rates shall be calculated according to the calculation algorithm laid out in the following chapter and can be carried out using the calculation template referred to in Annex C.

The algorithms for the calculation of rolling stock Recyclability and Recoverability Rates follow the flow of material shown in Annex D. The checklists given in Annex B are a guideline to help manufacturers in sorting the parts into the different process stages (i.e. pre-treatment, dismantling and shredding).

Once a part is classified for treatment in a certain process stage manufacturers are requested to decide whether the part is suitable for reuse or not (pre-treatment and dismantling stages only). The total mass of reused parts or components will then be considered for the Recyclability Rate.

If a part is not suitable for reuse, then it is necessary to know its material composition in order to allocate it to the different material categories stated in Annex A1. For that, train manufacturers are requested to obtain material information from part suppliers and keep a database containing this information for every significant part of the rolling stock and equipment.

Once a part is classified into a process stage, discarded for reuse and its material composition is known, the calculation algorithm will add up its material and all other materials of the same category coming from parts extracted at the same process stage. This algorithm simulates a process which in practice separates the part into its constituent materials and allocates together mass of the same category into the same container.

Once the materials for every phase are assigned, the calculation multiplies the total mass of each material category by the corresponding Material Recyclability Factor, MRF, of the corresponding process stage. MRF values for each material category and for each process stage are given in Annexes A2 to A4. This algorithm follows a process which in practice treats all the sorted materials in their corresponding recyclability processes whose efficiency is that of their corresponding MRF. If a material does not have a recyclability potential, the corresponding MRF is set to 0. The mass resulting after the addition of all the potentially recyclable materials multiplied by its recyclability factors is considered for the Recyclability Rate.

The sorted materials are also considered for energy recovery by means of the corresponding Energy Recovery Factor, ERF, of the corresponding process stage. ERF values for each material category and for each process stage are given in Annexes A2 to A4. Here the algorithm follows a process which in practice treats all the material for energy recovery, a process whose efficiency is taken into account by the corresponding ERF. The mass resulting after the addition of all the potentially recoverable materials multiplied by its energy recovery factors is considered for the Recoverability Rate of the rolling stock or equipment.

The mass that is left after the recycling and energy recovery processes is added as disposal. The disposal fraction for each material category in each process stage is calculated as the difference between 1 and the sum of the MRF and ERF. This is a measure of the inefficiency of the recycling and energy recovery processes for each particular material category at each process stage and will depend among other considerations, on the state of the art of the technology used for the separation and the processing of the materials.

The rest of this chapter describes the terms, definitions and equations that follow the calculation method described above.

5.1 Determining the partial Masses

For the determination of material masses use the method outlined in section 5.3 of ISO22628:2002 but in addition:

- For each treatment process in the ISO22628:2002 the mass of each material which can be reused, recycled or recovered shall be identified.
- For the material masses identified for recycling, multiply the mass by the corresponding Material Recyclability Factor (as shown in 4.3.1. of this document)
- For the material masses identified for energy recoverability, multiply the mass by the corresponding Energy Recoverability Factor (as shown in 4.3.2. of this document).

5.2 Recyclability Rate ($R_{(cyc)}$) and Recoverability rate ($R_{(\mathrm{cov})}$)

For calculation of the **recyclability rate**, use the formula from section 5.4.1 of ISO22628:2002 and substitute in the partial masses determined for recycling as calculated in 5.1 of this document.

For calculation of the **recoverability rate**, use the formula from section 5.4.2 of ISO22628:2002 and substitute in the partial masses determined for recycling, energy recovering and reuse as calculated in 5.1 of this document.

6 Design Recommendations to facilitate Recycling

The present chapter gives a series of recommendations to be taken into account at the design stage that will simplify and facilitate the end of life treatment process and therefore influence positively on the Recyclability and Recoverability Rates obtained by the calculation method. These recommendations are based on the so-called Ecodesign Pilot which is available online [6].

6.1 Pre-treatment and Dismantling

The following is a list of design recommendations to maximize the amount of material that can be extracted at the pre-treatment and dismantling stages in a safe and efficient way.

- The use of toxic substances should be avoided where possible during the whole life cycle for environmental reasons as well as for reasons of health. Toxic substances may have serious effects even if used in small quantities and should therefore be avoided, in particular, when they are or could be contained in accessible parts or components. It is therefore important to avoid such substances during the whole life cycle of a product or ensure easy extraction of particular substances.

- Parts to be dismantled parts should be described within a disposal concept or marked with special imprints.

- Material labelling shall be done, if possible, for polymer parts according to ISO 11469. The reason is to identify the polymer exactly and to classify it into a defined polymer fraction prior to the shredding process. Hence the Recyclability Rate can be increased.

- Easy access to connecting parts is a prerequisite for simple assembly and dismantling. Connecting parts should be arranged in such a way as to provide for good visibility and easy access with tools.

- Easily detachable connections reduce time consuming dismantling work. In addition, non-destructive dismantling is a prerequisite for the reuse of structural parts. If parts are damaged during dismantling only the material can be recycled; however, on account of the destruction of the material's structure this alternative yields less value than direct reuse of parts.

- Connecting parts that are not or not easily accessible greatly impair dismantling, either because the work requires special tools or dismantling is cumbersome and time consuming.

- Over time, external influences (aging, corrosion, soiling...) may impair the functionality of connecting parts. This makes it difficult or impossible to detach connections, thus complicating dismantling work considerably. Devices protecting connections from damage, such as covering caps over nuts and threads ensure detachability of connecting parts over the whole service life of the product.

The issues mentioned above are highly recommended for consideration in order to comply with the qualification list in Annex B. Following the aspects listed above can have a positive impact on calculation method results.

6.2 Material Recycling Factor MRF

For materials which can be recycled in principle the recycling process may be complicated if they are glued together or otherwise inseparably bonded to other materials. In this case, material separation would be impaired or even impossible at the dismantling stage, and will require shredding as the only way to treat the component at the end of the product life.

6.3 Energy Recovery Factor ERF

ERF mostly depends on the heating value of material to be incinerated. In general the recycling shall be preferred to an incineration process with energy recovery.

Energy recovery should always be the last option for materials. Energy recovery emits not only energy for heating and electrification but also greenhouse gas emissions and harmful substances such NO_x and SO_2.

- To avoid harmful emission the material content must be free of coverings and other toxic substances.

- Energy recovery requires the use of combustible organic materials. If the product contains incompatible materials these should be separable. Design should ensure easy separation of materials intended for incineration.

7 References

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Annexes

Annex A: Material information - Factors MRF and ERF

The selected material categories and given MRF/ERF are recommended to use as they represent the state-of-the art knowledge. The details provided here may, however, be subject to change.

A1: Material categories

To calculate recycling figures it is essential to have a database of materials classified into categories from the design phase of the rolling stock product. The calculation method for the Recyclability and Recoverability Rates assigns the materials to the categories shown in Table 1 below. For the purpose of this document thermoplastics are defined as ductile and shapeable under heat. Thermosets are defined as polymers which are not ductile and shapeable under heat and undergo chemical decomposition, see Table 2.

Table 1: Material categories

Index	Material categories considered in rolling stock calculation method
1	FE metals
2	Non-FE metals
3	Elastomers (unfilled)
4	Thermoplastics (unfilled)
5	Thermoplastics (glass filled)
6	Thermosets (unfilled)
7	Thermosets (glass filled)
8	Carbon or natural fiber reinforced polymers
9	Glass
10	Safety Glass (shatterproof glass)
11	Oil, grease or similar
12	Acids and Cooling agents or similar
13	MONM (leather, wood, cotton fleece …)
14	Electric /
15	Ceramics
16	Mineral wool

Table 2: Commonly used thermosets and thermoplastics

	Thermosets	Thermoplastics
Reinforced by	Glass fibres	
	Natural fibres	
Matrix	Epoxy resin	Polyethylen PE
	Phenolic resin	Polyamid PA 6
	Polyester resin	Polytetrafluorethylen PTFE
		Polyamid 6.6
		Polycarbonat PC
		Polyurethane PUR
		Polyvinychlorid PVC
		Acryl Butadien Styrene ABS Polypropylene PP Polystyrene PS

A2: Factors MRF and ERF for Pre-treatment

The pre-treatment is the first step in a row of process stages whose purpose is to collect and separate all toxic and explosive substances or gases which can be harmful to human health and environment from the vehicle. These materials are found in categories 11, 12 and 14 in Table 1 above, i.e. oil, grease, acids and other fluids and electric/electronic components. The values of MRF, ERF for these material categories are defined in the following table.

Table 3: MRF and ERF for pre-treatment

Index	**11**	**12**	**14**
Material category	**Oil, grease or similar**	**Acids and Cooling agents or similar[7]**	**Electric / Electronic[8]**
MRF	0%	83%	79%
ERF	100%	0%	19%
Residue	0,0%	17%	2%

A3: Factors MRF and ERF for Dismantling

The dismantling step separates as much material as possible before the shredding step. All the fluids that have been previously treated in the pre-treatment phase, categories 11 and 12, are not included here because they should no longer be present. The electric and electronic parts that have not been separated in the pre-treatment phase should be collected during the dismantling phase.

Table 4: MRF and ERF for dismantling

Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Material category	**FE metals[9]**	**Non-FE metals [10]**	**[11]**	**Thermoplastics (unfilled) [2]**	**Thermoplastics (glass filled)[12]**	**Thermosets (unfilled) [2]**	**Thermosets (glass filled)[12]**
MRF	98%	98%	80%	100%	66,7%	100%	66,7%
ERF	0%	0%	20%	0%	33,3%	0%	33,3%
Waste	2%	2%	0%	0%	0%	0%	0%
Index	**8**	**9**	**10**	**13**	**14**	**15**	**16**
Material category	**Carbon or natural fibre reinforced polymers[12]**	**Glass[13]**	**Safety Glass (shatterproof glass)[14]**	**MONM (leather, wood, cotton fleece …) [2]**	**Electric / Electronic[8]**	**Ceramics[7]**	**Mineral wool[15]**
MRF	66,7%	100%	94%	95%	79%	43%	97%
ERF	33,3%	0%	0%	5%	19%	0%	0%
Residue	0%	0%	6%	0%	2%	57%	3%

[2] Potential values

A4: Factors MRF and ERF for Shredding and post-shredding process

The mass flow after the shredding process is separated into its metal constituents and its non-metal fraction called the Shredder Light Fraction, SLF. Since SLF is in practice treated as a unique fraction and not sorted out into its different materials categories, it is also treated as one material category for the calculation. Table 5 gives MRF and ERF values for the FE metal and non-FE metal as well as SLF categories after the shredding process. Values for the Mixed materials category have been chosen according to [16] from which the Galloo process has been selected.

Table 5: MRF and ERF for shredding post-shredding process

Index	1	2	-
Material category	**FE metals[9]**	**Non-FE metals [10]**	**Mixed materials [16]**
MRF	98%	98%	14%
ERF	0%	0%	19%
Residue	2%	2%	67%

Annex B: List of Qualification Criteria

The qualification criteria list supports the processes pre-treatment and dismantling as described in chapter 5.1 and 5.2.

1. Follow the flowchart shown in Figure 4. At first the entire train will be pre-treated. Following the recommendations in section 6.1 above, the materials and components listed in Table 6 below should be removed during the pre-treatment steps because they could be harmful for human and environment.

2. After the pre-treatment stage, no substances which can influence the recycling process in a negative way shall remain inside the vehicle, so that the next step – dismantling – can be applied without any risk.

3. Table 7 is a list of criteria to help in making the decision on whether to dismantle a particular component from the vehicle for further recycling steps or leave it on the vehicle for the shredding process.

Table 6: Parts to be removed during pre-treatment

Material, substance, part	Criteria	Dismantling/ Drainage
Fluids	Present	YES
Gases, explosives	Present	YES
Catalytic capacitors	Present	YES
Pollutants and hazardous substances	Present	YES
Fire extinguisher	Present	YES
Braking sand	Present	YES
Batteries	Present	YES, use take-back system
Greases	Present	YES
Oil	Present	YES
Other substances which can influence the recycling process		

Table 7: Qualification list for dismantling

Aspects of Recycling	Criteria for dismantling a component or material	Dismantling
Are there any components which can be reused?	Component is present	YES, REUSE step
Accessibility of the component	Directly accessible	YES
	Indirectly accessible	YES
	Inaccessible	NO, though value of material needs to be taken into account
Time to dismantle component	Low	YES
	Considerable time consumption	YES
	Very high	NO, though value of material needs to be taken into account
Type of connections	Non-destructively detachable	YES
	Partially destructive	YES, but additionally depending on dismantling time and value of material
	Destructive, including damage to component	NO, though value of material needs to be taken into account
Valuable material	Present	YES
	Not present	NO
Is a state of the art recycling process for the material available?	Optimum process available	YES
	Complex process steps required	NO, though value of material needs to be taken into account
	No process available for material recycling	NO, keep in the vehicle for further processes
Is the material marked according to ISO 11469?	Polymer is marked	YES
	Component is only partly marked	YES
	Not marked	NO, only if the material is known and a state of the art process for recycling is available

Annex C Recycling Calculation Template

UNI-LCA-002.00_Recycling_Calculation_template

Annex D: Recycling process flow chart

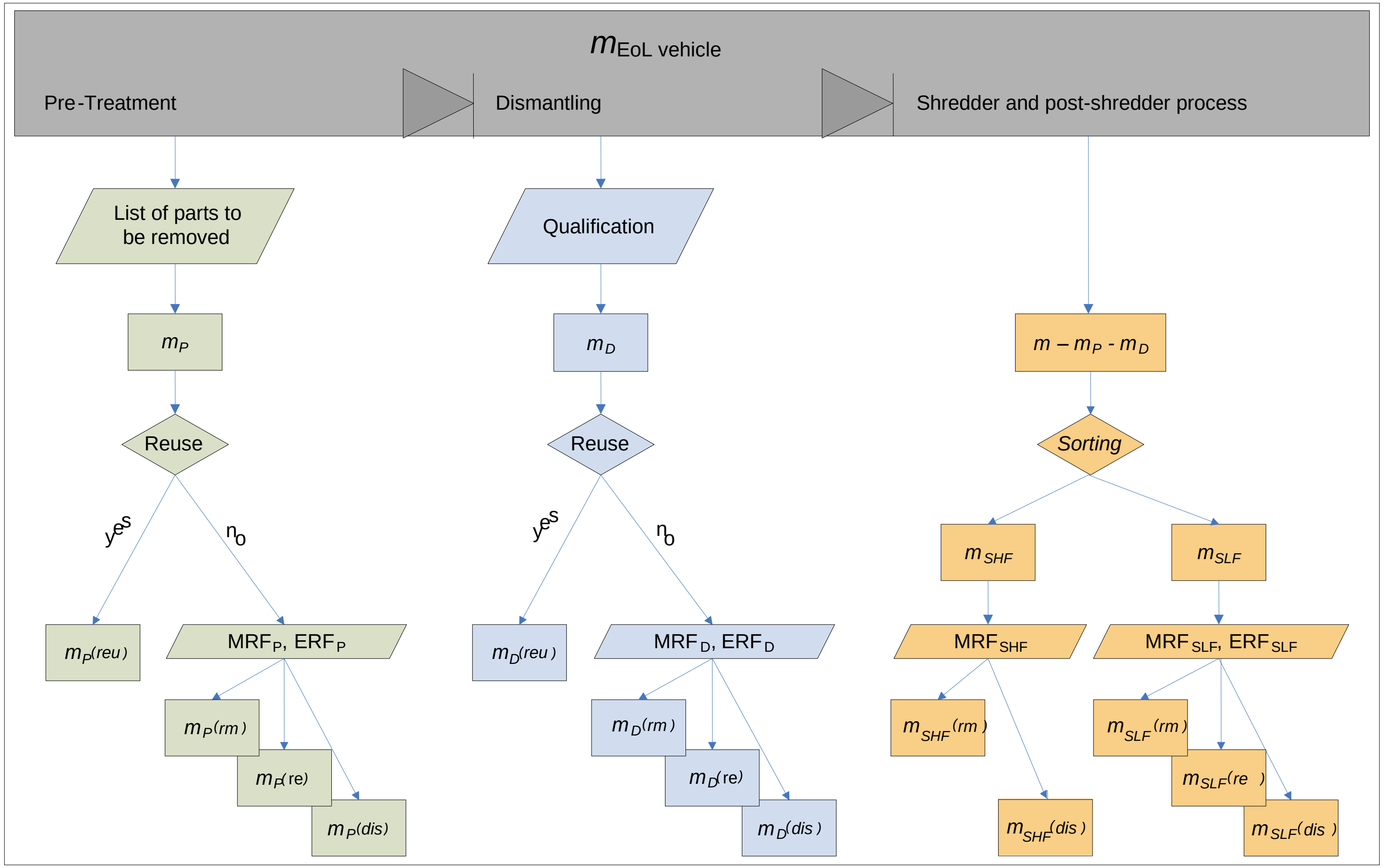

Figure 4: Recycling process flow chart