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UNIFE guidelines for ISO 21106:2019 “railway applications: recyclability and recoverability calculation method for rolling stock”

By UNIFE Life-Cycle Assessment Topical Group (LCA TG) - April 2025

About UNIFE and the content of this document

UNIFE, the *European Rail Supply Industry Association*, has operated in Brussels since 1992, representing European train builders and rail equipment suppliers. The association advocates for more than 115 of Europe's leading rail supply companies – from SMEs to major industrial champions – active in designing, manufacturing, maintaining and refurbishing rail transport systems (trains, metros, trams, freight wagons), subsystems and related equipment. UNIFE also brings together national rail industry associations from 12 European countries.

UNIFE's ***Sustainable Transport Committee*** (STC) brings together the rail supply industry's leading experts on sustainability-related topics. The STC defines the strategy and carries out UNIFE's activities in the fields of sustainable mobility, climate crisis, energy efficiency, urban mobility, circular economy, sustainable finance (EU Taxonomy) and any other relevant EU policy initiative. The STC coordinates the activities of a technical expert body named the ***Life-cycle Assessment Topical Group*** (LCA TG).

The LCA TG focuses on life-cycle-based assessments of railway systems considering all kinds of environmental impacts (CO_2, Photochemical Smog, Ozone depletion, etc.), Ecodesign, Product Category Rules (PCR) for Environmental Product Declarations (EPD), Ecolabel & Eco-procurement, standardisation and legislative requirements for specific eco-related topics. It updates technical documents.

End-of-life treatment and environmentally sound waste disposal are crucial for the railway industry. A common approach is needed to ensure railway equipment's efficient recycling and reporting. In 2009, the UNIFE STC developed a recycling calculation method for the specific needs of the railway industry. In 2014, the *International Standardization Organization* (ISO) launched an expert group to create a standard based on the UNIFE methodology. It resulted in the **ISO 21106:2019 - *Railway applications — Recyclability and recoverability calculation method for rolling stock***.

The document below aims to help understand ISO 21106, including recommendations for separating complex products, material recycling factors, energy recovery factors, etc.

The *UNIFE guidelines for ISO 21106:2019* are a UNIFE document that applies to the rolling stock manufacturing industry.

This document contains only general descriptions or performance features. They may change due to specific applications or further development of the products or technology. The descriptions, data, and features contained herein are to be understood as general recommendations and should not be used as legally binding contractual documents.

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Normative references

- EN 15380-2 - Railway applications - Designation system for railway vehicles - Part 2 product groups – 2006.
- Environdec - PCR 2009:05 - Product Category Rules for preparing an environmental product declaration (EPD) for rail vehicles - UNCPC CODE: 495.
- European Union - Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.
- European Union - Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.
- European Union - COM 2000/532/EC - Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C(2000) 1147).
- European Union - Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC.
- European Union - Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
- European Union - Restriction of the use of certain hazardous substances (RoHS) - Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast).
- European Union - Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast).
- European Union - Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC.
- ISO 11469:2016 Plastics - Generic identification and marking of plastics products
- ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework.
- ISO 21106:2019 Railway applications - Recyclability and recoverability calculation method for rolling stock.
- UIC - 345/E/1 - Environmental specifications for new rolling stock – 2006.
- VDI 2243 - Recycling-oriented product development – 2002.

Introduction

This document aims to guide UNIFE members and their suppliers in applying ISO 21106, the standard establishing a common rail industry method to make recyclability and recoverability figures comparable and transparent within the railway industry. **The purpose of this document is not to recommend minimum values for recyclability and recoverability.**

Terms and definitions

Component means a uniquely identifiable product that cannot be disassembled without being destroyed and considered indivisible for a particular purpose.[1]

Disposal covers the final placement of wastes under proper process and authority with (unlike in storage) no intention to retrieve them. The concept includes any operation that is not recovery, even where the reclamation of substances or energy is a secondary consequence. Disposal may be accomplished by, e.g., deposit into or onto land, incineration, deep injection, or permanent storage.

Energy recovery is the process of generating energy. It depends on the heating value, the efficiency factor, and the use of the reached energy.

Incineration is the combustion process without using the distribution of the energy potential related to incinerated substances and with a high focus on reducing the volume of waste.

Landfill means a waste disposal site for depositing waste onto or into land (i.e. underground), including internal waste disposal sites and permanent sites (i.e. more than one year) but excluding waste storage prior to recovery, treatment or disposal for a specified period.[2]

Material is the substance or substances of which an object is made or composed. Composite materials made from more constituent materials are also considered.

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[1] Definition according to EN 15380-2.

[2] Definition according to Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

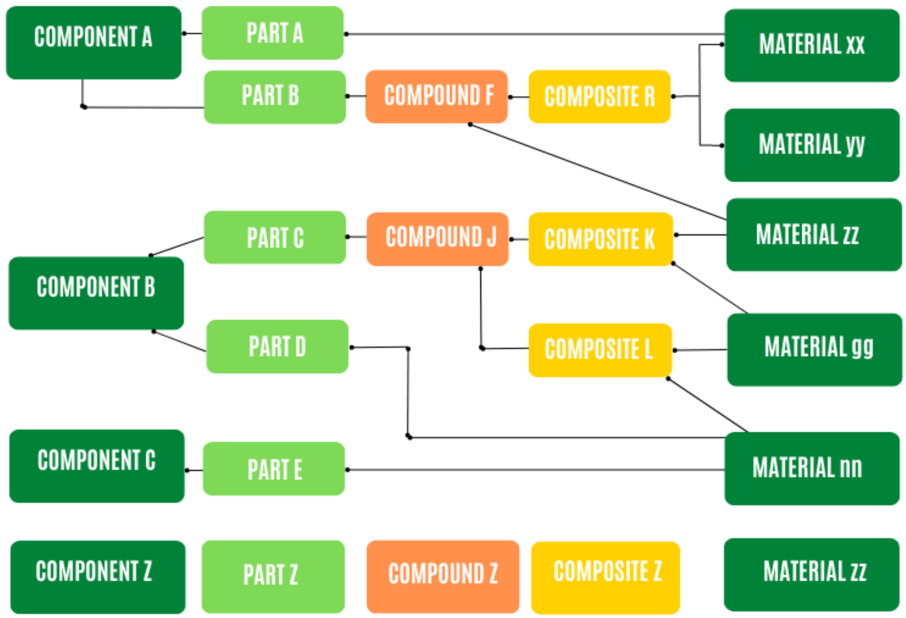

Figure 1: Structure, relation and combination of component, part, compound, composite and material

Part is the smallest dismantable unit of a component.

Product means any goods or services categorised as follows:

- services (e.g. transport);
- software (e.g. computer program);
- hardware (e.g. engine mechanical part);
- processed materials (e.g. lubricant).[3]

Recover means processing waste materials in a production process for the original purpose or other purposes, including processing as a means of generating energy. **Energy recovery** differs from recovery in that it only includes processing the waste materials to generate energy.[4]

Recoverability means the suitability of components or materials to be diverted from end-of-life treatment to be recovered.[5]

Recycling means processing waste materials for their original or other purposes, excluding processing to generate energy.[6]

Reuse means any operation by which components or parts of railway vehicles are used for the same purpose for which they were conceived.

[3] Definition according to ISO 14040:2006.
[4] Definition according to ISO 21106:2019.
[5] Definition according to ISO 21106:2019.
[6] Definition according to ISO 21106:2019.

A sub-product group performs a sub-function of a component/assembly within the framework of a primary function.[7]

Substance means a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used. Yet, it excludes any solvent which may be separated without affecting the stability of the substance or changing its composition.

Treatment means recovery or disposal operations, including preparation prior to recovery or disposal.

Waste means any substance or object in the categories set out in Annex I - Directive 2008/98/EC that the holder discards intends, or is required to discard.[8]

[7] Definition according to EN 15380-2.
[8] Definition according to Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

Scope

The calculation method related to ISO 21106:2019 shall cover only the end-of-life stage of rolling stock. The calculation shall be carried out for rolling stock 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 considered. The calculation method does not cover infrastructure systems like stations, electrification, signal and control units, etc. On a voluntary basis, it is possible to use it as a methodology for calculating the recyclability and recoverability of the infrastructure system.

This calculation method can be applied to all types of rolling stock according to PCR 2009:05.

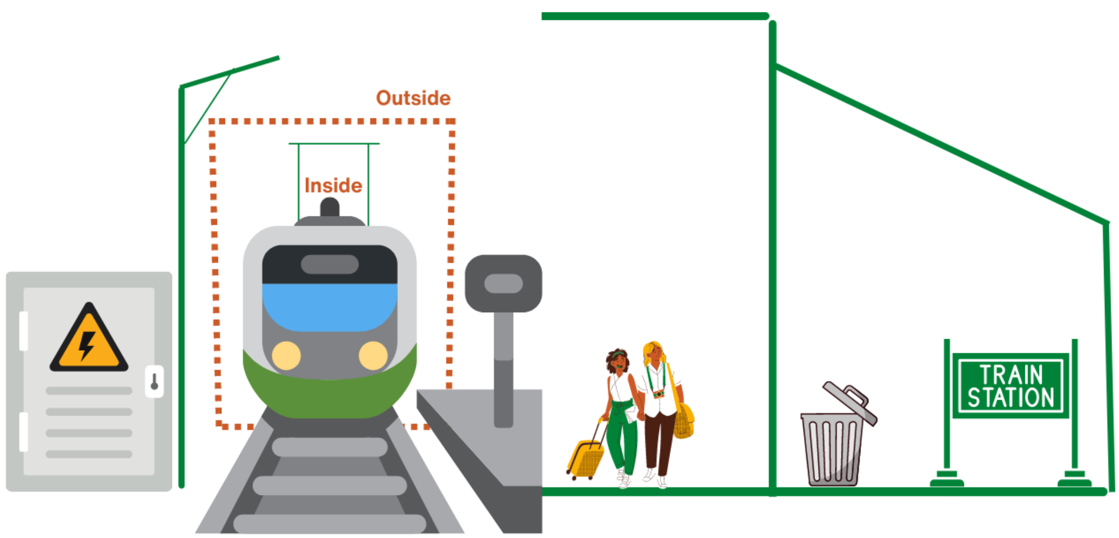

Figure 2: Scope of systems included, shown in red frame

Technical boundary

The calculation method covers all types of rolling stock and their components as delivered. The recycling technologies are based on the four main treatment processes: reuse, recycling, energy recovery and disposal. Process losses of recycling will be treated in the disposal stage. In the energy recovery stage, the residue materials of the incineration process, mostly ash and slag, will be landfilled.

According to the ISO 21106 chapter on “breakdown material”, all materials must be allocated to defined material categories.

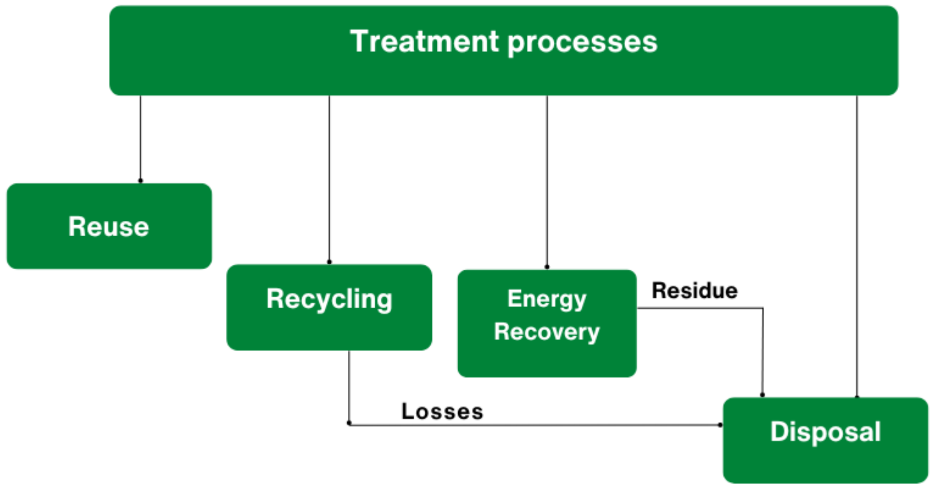

Figure 3: Schematic process of treatment steps

Chronological boundary

The year of manufacturing is not limited by the scope. Thus, if data is available, the calculation method can also be applied to older rolling stock and equipment types.

These calculated recycling and recoverability rates are valid at the point of calculation for the specific rail vehicle or components. The results reflect current recycling practices and cannot predict the actual technology in 30 years (the average lifetime of a rail vehicle).

Calculated figures can also be applied to other life cycle stages (e.g., manufacturing). All given data will be valid only for unmodified rolling stock equipment. The method is based on available information about current recycling technologies and standards. It does not include future recycling technologies or predicted trends related to the recycling industry.

Geographical boundary

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

How to apply the ISO 21106

The holistic recycling process involves three relevant steps or stages of treatment during the end of life of the rolling stock procedure at common recycling plants. The process starts with the pre-treatment step. It is followed by dismantling and, finally, the shredder. This process is aligned with the one described in ISO 21106.

In all steps, different policies and requirements should be considered to ensure no damage to humans and the environment. Due to different sorting and shredder technology, wide variations of efficiencies occur. Following the different recycling steps generates a variable amount of residue, which must be considered when calculating the recoverability and recyclability rates.

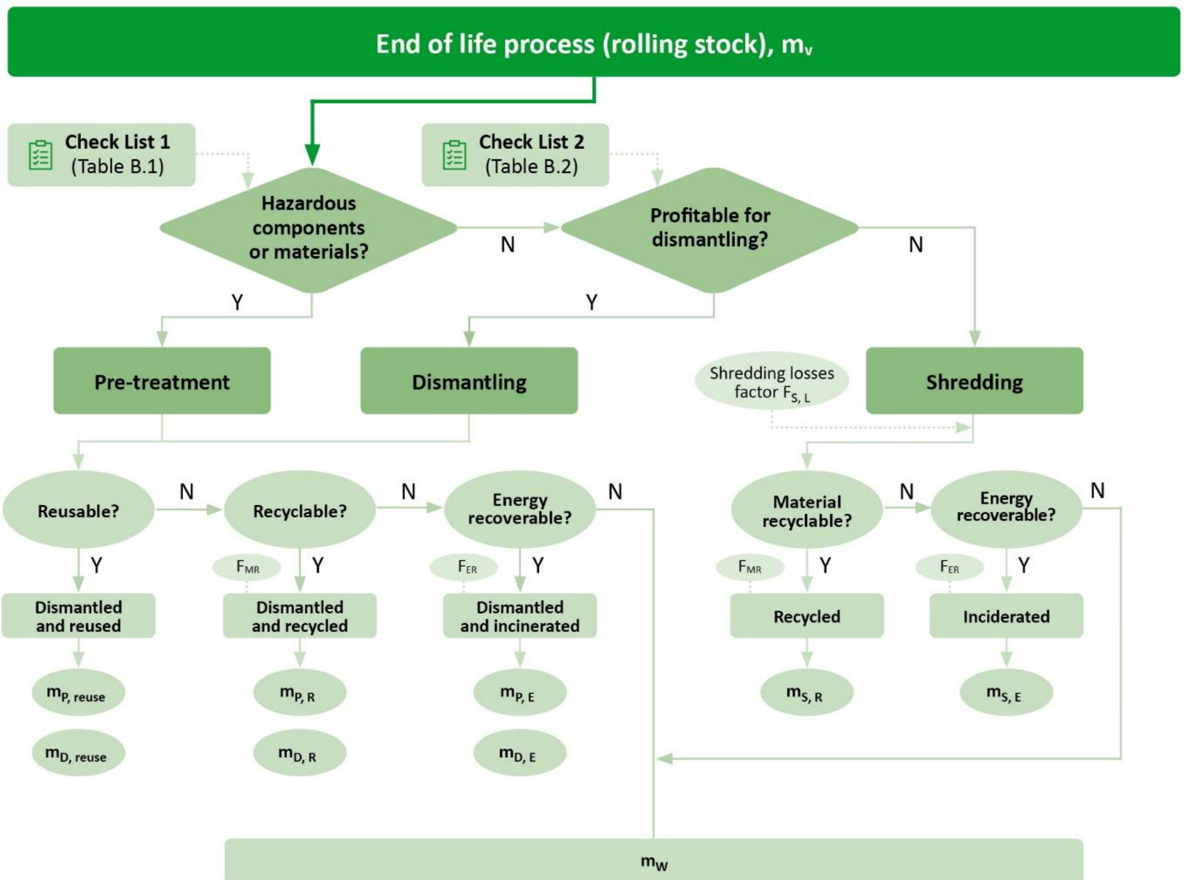

Figure 4: Steps of the recycling process during the end of end-of-life procedure of rolling stock and equipment[9]

Read ISO 21106 chapter 5, “End-of-life treatment process”, for more details.

[9] Source: ISO 21106:2019

How to apply for the pre-treatment and reuse

Pre-treatment is the first step in a row of process stages. Pre-treatment aims to extract toxic and explosive substances that can harm humans and the environment.

The pre-treatment stage starts with the checklist Table B.1 in ISO 21106. There will be no claim to completeness to all harmful substances and materials. It is recommended to evaluate the presence of hazardous components or materials using the Bill of Materials (BOM).

If hazardous components or materials cannot be extracted without dismantling, the relevant component must be removed and treated as a separate component. Thus, the respected component must be re-evaluated via Table B.1 until all hazardous materials have been removed.

Examples:

1. Lead in electronics: all electronic parts must be dismantled and treated in a specific waste stream.
2. Built-in batteries need to be dismantled and removed as a whole, e.g. lightning system (including light source, cables, housing, etc.).

There are also components which are intended for reuse.

All the extracted substances, materials, and components must be considered in the calculation as pre-treated mass and shall be classified according to ISO 21106 into reuse ($m_{P,Reuse}$), recycle ($m_{P,R}$), energy recovery ($m_{P,E}$), or disposal (m_w) depending on the nature of each material and once the loss factors (F_{MR} and F_{ER}) have been applied.

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.

How to apply dismantling

After successfully removing the harmful materials and components, the checklist Table B.2 in ISO 21106 for dismantling should be applied to the remaining vehicle and components.

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 those within the shredding residue.

All the dismantled materials and components must be considered in the calculation as dismantled mass. They shall be classified according to ISO 21106 into reuse ($m_{P,Reuse}$), recycle ($m_{P,R}$), energy recovery ($m_{P,E}$), or disposal (m_w)depending on the nature of each material and once the loss factors (F_{MR} and F_{ER}) have been applied.

In best practice, the component's supplier or producer should provide information on the components to be considered for dismantling. The relevant component's supplier or producer should determine the dismantling's feasibility.

Parts and components like windows, seats, floors, cables and electronic parts, heating, ventilation, and air conditioning (HVAC) are typical examples that shall be considered at the dismantling stage before the shredder process. Electronic parts should be handled as electronic and electrical scrap with specific treatment processes and sorting technologies.

How to apply shredding and which parts to use

After the pre-treatment and dismantling stages, the remaining components, parts, compounds, and materials enter the shredding process. The shredding process can be applied to various components, parts, compounds or materials. However, the non-qualified parts and components shall be processed in the shredding stage.

All the shredded materials and components must be considered in the calculation methodology as shredded mass and shall be classified according to ISO 21106 into recycle ($m_{S,R}$), energy recovery ($m_{S,E}$) or disposal (m_w) depending on the nature of each material once the shredding loss factor (F_{SL}) and the loss factors (F_{MR} and F_{ER}) have been applied.

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

Efficiency of the recycling process

The suitability for recycling or energy recovery of the materials used for rolling stock and equipment is essential when calculating the potential Recycling and recovery rates. The material recycling factor (F_{MR}) and the energy recovery factor (F_{ER}) consider such suitability to be recycled or recovered. Materials presenting better suitability for recycling or energy recovery will improve the overall recycling or recovery rate of rolling stock and equipment.

The material recycling factor (F_{MR}) displays the current efficiency/ratio of the **mass-related possibility of recycling materials**. For example, if 1 kilogram of homogenous steel is scraped and melted, the output yield will be close to 1 kilogram of secondary steel. This loop of recycling can be extrapolated many times. Thus, steel will have the potential to be an excellent recyclable material. High F_{MR} means less material to waste.

The energy recovery factor (F_{ER}) is the efficiency of process based on material weight to be recovered as usable energy. High F_{ER} means less material to waste.

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 to help manufacturers make those decisions. The qualification is based on specific criteria such as joining technology, accessibility, toxicity, dismantling time, economic feasibility and environmental impact.

Furthermore, the manufacturers are encouraged to study the technical and economic feasibility and the environmental evaluation of their recycling strategy 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 can allocate more components into the dismantling stage, improving the product's recyclability and recoverability rates.

For now, it is more efficient and economical to process the dismantled parts than the shredder residue; thus, recycling and energy recovery processes are more efficient for components dismantled before the shredding phase.

The shredding losses factor (F_{SL}) is defined as the losses during the process, such as mechanical separation in the shredder mill.

Table 1: shredder efficiency values for ISO 21106

Separation technology/process	Shredder efficiency	Shredding losses factor (ShLf)	Description
Magnetic separation	80% - 100%	0% - 20%	**Magnetic separation** is the process of separating components of mixtures by using different types of magnets to attract ferromagnetic materials. It detaches non-magnetic materials from magnetic materials. Magnetic separation is mainly used to recover metal from waste or purify secondary materials by removing metals. It is also used in electromagnetic cranes that separate magnetic material from scraps and unwanted substances. In the recycling industry, magnets are commonly used to attract ferrous materials such as tin, iron, steel, and many more. Magnets are found along assembly lines, placed above or below the conveyor belts to attract materials or minerals.[10]
Flotation	70% - 90%	10% - 30%	**Selective flotation** is a physicochemical process based on the selective adhesion of specific solid particles according to their surface property. The mixed solid particles and liquid medium (e.g., water) are conditioned with chemical reagents to differentiate each solid particle's surface properties and promote the selective formation of aggregates between solid particles and air bubbles. The system then gradually fills with

[10] Source: https://recyclinginside.com/recycling-technology/separation-and-sorting-technology/

			atmospheric air to produce air bubbles, attaching with more hydrophobic particles. Hydrophobic particles float to the water surface (floated product), and hydrophilic particles remain in the water (non-floated product).[11]
Electrostatic separation with an optical system	80% - 90%	10% - 20%	Mixed plastics can be recognised based on their colours. Various sensors that recognise plastics based on colour are used. These sensors' capabilities extend beyond the visible light spectrum and include detection in infrared, ultraviolet, and other frequency ranges. The following optic sensor-based separation devices are used: near-infrared (NIR), a colour line camera, and X-ray fluorescence. The optic sensor equipment separates materials such as individual plastic polymers, e.g., polyethylene (PE), poly(vinyl chloride) (PVC), poly(ethylene terephthalate) (PET), and acrylonitrile butadiene styrene (ABS).[12]

For more information on innovating processes, please refer to the “Top 8 Recycling Technology Trends & Innovations”.[13]

Recommendations for F_{MR} and F_{ER} values

If no data for F_{MR} and F_{ER} is available, use the following values for specific materials. Table 2 figures out default values. Use your own data or any more accurate data if applicable.

Table 2: F_{MR} and F_{ER} values for materials

Material Families	F_{MR}	F_{ER}
Fe Metals[14]	99%	0%

[11] Source: https://www.mdpi.com/2313-4321/7/4/44
[12] Source: https://www.mdpi.com/1424-8220/20/24/7201
[13] Source: https://www.startus-insights.com/innovators-guide/recycling-technology-trends-innovation/
[14] Bowyer et al. (2015) mention that several industry sources describe steel as "**100% recyclable** at the end of its long life." In theory, steel is infinitely recyclable, but in practice, there are several limitations, such as recycling technologies and the presence of various alloys.
Source: Bowyer, Jim & Bratkovich, S. & Fernholz, Kathryn & Frank, M. & Groot, Harry & Howe, J. & Pepke, Ed. (2015). *Understanding Steel Recovery and Recycling Rates and Limits to Recycling*. Dovetail Partners Outlook. p. 7-9 – available here.

Non-FE Metals[15]	99%	0%
Elastomer[16]	No data available	No data available
Polymers - Thermosets[17]	35,9%	67,8%
Polymers - Thermoplastic[18]	35,9%	67,8%

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[14] **Steel** making is nearing zero waste, with current material efficiency rates at **97.5%.** This means that over 97% of raw materials used on-site are converted to products and co-products that are used or recycled. Source: *Fact-sheet-raw-materials-2023.pdf (worldsteel.org)*.

[14] According to the report *"Acciaio protagonista dell'economia circolare. La sostenibilità in Italia: riciclare, ridurre e far durare."* by *Fondazione Promozione Acciaio*, the **steel treatment processes allow 99% of it to be recycled**. https://www.promozioneacciaio.it/UserFiles/File/pdf/comunicati/Articolo%20acciaio%20economia%20circolare%20-%20Maggio%202019.pdf

[14] Steel parts in the train are big, heavy (the bogies for instance) and can be clearly identified. The steel parts that cannot be easily isolated and separated (so sent to shredding process) represent a very low percentage of the whole weight of all parts made of steel in the rail. This is the main reason why higher percentage in recycling rate of steel coming from rail end-of-life can be performed.

[15] Raabe et al. (2022) state that the yield in scrap-based **aluminium** production is very high, at **about 98%**, as the metal lost during recycling processes is usually below 2% once collected. Source: Dierk Raabe, Dirk Ponge, Peter J. Uggowitzer, Moritz Roscher, Mario Paolantonio, Chuanlai Liu, Helmut Antrekowitsch, Ernst Kozeschnik, David Seidmann, Baptiste Gault, Frédéric De Geuser, Alexis Deschamps, Christopher Hutchinson, Chunhui Liu, Zhiming Li, Philip Prangnell, Joseph Robson, Pratheek Shanthraj, Samad Vakili, Chad Sinclair, Laure Bourgeois, Stefan Pogatscher, *Making sustainable aluminum by recycling scrap: The science of "dirty" alloys*, Progress in Materials Science, Volume 128, 2022, 100947, ISSN 0079-6425, https://doi.org/10.1016/j.pmatsci.2022.100947.

[15] Lux et al. (2021) state, "**Up to 98%** of these metals [**Non-ferrous Metals**] can be completely recovered and converted to pure products." Source: *Recycling of Non-ferrous Metals – A Key Enabler for the Circular Economy* Timm Lux, Rolf Degel, Markus Reuter Article in World of Metallurgy - ERZMETALL July 2021.

[15] For aluminium, with the progress of technology, an ever-increasing number of remelters (remelting ovens) are able to use painted or polymer-containing scrap, practically never resorting to preparation processes. A double chamber oven is generally used: the aluminium finishes (such as paints) are burned in the first of the two chambers whose emissions into the atmosphere are reduced by pollutants using efficient fume treatment system equipment (https://aluminium.org.au/). The metal melting heat treatment takes place in the second chamber. From here in the liquid state it can be sent directly to foundries or cast into ingots, billets for extrusion or plates for rolling, ready to start a new life. The efficiency of these systems is **close to 100%**.

[15] Where the copper does not present contamination from other metals as in the case of most of the cables used in vehicles, the **efficiency** of the processes for separating the waste copper from the impurities represented mostly by the insulating polymers is extremely **high and close to 99%**. Most of cables are positioned along the backbone of the vehicle and can easily separate.

[15] The content of metals in electronic parts of the rolling stock is in any case very low if compared with the overall content of metals in the train, much less than 1%. Also the electric engine contains copper. In this case the actual recycling rate is **no less than 95%** (https://www.youtube.com/watch?v=p34THyf9zLs). The weight of copper in motor windings represents, in general, less than 10% of the overall weight of copper in the train; thus not significantly affecting the global separation efficiency of copper in recycling process at end-of-life of the train.

[16] Giorgia Faraca, Thomas Astrup, *Plastic waste from recycling centres: Characterisation and evaluation of plastic recyclability*, Waste Management, Volume 95, 2019, Pages 388-398, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2019.06.038.

The Circular Economy for Plastics – A European Analysis – Plastics Europe – March 2024 - The Circular Economy for Plastics – A European Analysis 2024 • Plastics Europe

[17] Ibidem

[18] Ibidem

Composites[19]	ND	ND
Electric and electronic equipment	No data available	No data available
Glass[20]	100%	0%
Safety glass[21]	100%	0%
Oil, grease or similar[22]	61%	ND
Acids, cooling agents or similar	No data available	No data available
Other inorganic materials[23]	80%	0%
Mineral wools[24]	100%	0%
Modified organic natural materials, including wood[25]	100%	0%

For more information on recycling-oriented product development, please refer to the "Recycling-oriented product development", a standard developed by VDI[26].

[19] EuCIA welcomes industry to complete composites waste and recycling survey | CompositesWorld

[20] Basudev Swain, Jae Ryang Park, Dong Yoon Shin, Kyung-Soo Park, Myung Hwan Hong, Chan Gi Lee, *Recycling of waste automotive laminated glass and valorisation of polyvinyl butyral through mechanochemical separation*, Environmental Research, Volume 142, 2015, Pages 615-623, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2015.08.017.

[21] Ibidem

[22] Klenert et al, 2024, Quote: *" In 2018, 1.6 million tonnes of waste oil were collected in the European Union. About 61% of the waste oil was regenerated – i.e. it was turned into base oil again – and 39% followed energy recovery pathways either in the form of conversion to fuel or via direct incineration."* Source: D. Klenert, P. García-Gutiérrez, D. Tonini, H. Saveyn & R. Marschinski (27 Feb 2024): *The economics of waste oil recycling in the EU*, Journal of Environmental Economics and Policy, DOI: 10.1080/21606544.2024.2318385

[23] Electrodynamic fragmentation: selectively separating materials with "flashes" instead of just crushing - Fraunhofer Institute for Building Physics IBP

[24] Source: https://www.isover-technical-insulation.com/recycled-building-material

[25] Source: https://recyclinginside.com/wood-recycling/#:~:text=Yes%2C%20most%20wood%20waste%20can,used%20profitably%20as%20a%20fuel.

[26] VDI 2243 - Recycling-oriented product development – 2002.