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CAR TO CAR STEEL

Potential of End-of-Life Vehicle deep-dismantling and use of copper depolluted steel scrap to decarbonize automotive flat steel production

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INSTITUT MOBILITÉS EN TRANSITION

REPORT

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CAR-TO-CAR STEEL

POTENTIAL OF END-OF-LIFE VEHICLE DEEP-DISMANTLING AND USE OF COPPER DEPOLLUTED STEEL SCRAP TO DECARBONIZE AUTOMOTIVE FLAT STEEL PRODUCTION

Hannah Gross, Jean-Philippe Hermine

EXECUTIVE SUMMARY

Decarbonizing mobility is essential and requires simultaneously leveraging efficiency, modal shift and vehicle electrification. At the same time, reducing the production footprint of vehicles is amongst those pivotal levers. Addressing embedded emissions in materials and supply chains is even more critical for electric vehicles for which environmental residual impact concentrates in the manufacturing phase. Steel decarbonisation is a particular priority, as it is the most widely used material in cars and trucks and the second-largest contributor to greenhouse gas (GHG) emissions in vehicle manufacturing.

Beyond reducing emissions in primary steel production through the development of Electric Arc Furnaces (EAF) using Direct Reduced Iron (if produced with green H_2), vehicle steel emissions and material footprint can be significantly reduced by increasing the use of secondary (recycled) raw materials. Closing this circularity loop would prevent downgraded recycling to lower-quality steel grades and would usefully complement the shift from coal-based blast furnaces (BF-BOF) to the DRI-EAF route. EAFs can incorporate a significantly higher proportion of steel scrap than the BF-BOF route, including for demanding production processes (e.g. high-quality flat steel used for car body stamping). Notably, the automotive manufacturing market is widely recognized as the primary sector (lead market) poised to absorb decarbonized steel production.

In parallel, the Circular Economy is a key pillar of the Clean Industrial Deal released by the European Commission in February 2025, aiming to enhance industrial autonomy and competitiveness in Europe. Additionally, the concept of circularity is particularly reflected in the Commission's proposal for a regulation on circularity requirements for vehicles and the management of end-of-life vehicles (ELVs). This regulation includes a provision mandating a minimum recycled steel content in new vehicle production. Similar requirements would apply to other materials, such as plastics and aluminum, with a potential prerequisite that a portion of recycled content originates from ELV treatment. This report examines the feasibility and relevance of this ambition, highlighting its importance for resource efficiency (both for steel and copper), as well as its strategic implications for resilience and competitiveness within the European industry.

The proposed regulatory direction, which aligns with the commitments of many European carmakers to increase recycled materials in their vehicles, still raises questions regarding the most relevant technical approach and its economic implications. More specifically, it requires assessing how to increase and maintain the technical and economic value of ELV steel scraps, particularly those categorized as "E40" scrap (post-consumer shredded scrap, as opposed to pre-consumer scrap or stamping production scrap "E8" which is another scrap category generated during vehicle manufacturing).[1] A key challenge is the level of copper contamination in E40 scrap, which limits the extent to which it can be incorporated into new flat steel production.[2] Copper, present in ELVs as wiring and electrical components (in addition to being sometimes naturally present in steel), is the primary pollutant in ELV steel scrap. At the same time, paradoxically, copper is globally recognized as a critical material for the energy transition, making the current losses in Europe's ELV treatment process unsustainable.

To provide independent and holistic insights, the Institute for Mobility in Transition (IMT-IDDRI) has studied the technical and economic feasibility of closed-loop ELV steel scrap recycling for high-quality automotive flat steel production. IMT conducted a deep-dismantling project to assess whether enhanced copper removal from ELVs can improve scrap quality to the level required for reintegration into DRI-EAFs for high-end flat steel grades, while maintaining a viable business model for stakeholders across the recycling value chain.

Achieving closed-loop circularity would address three key challenges: (i) reducing primary raw material consumption, (ii) lowering the GHG footprint of new vehicle production, and (iii) providing flexibility in the EAF supply chain by enabling partial replacement of DRI with high-quality shredded steel scrap, if available in sufficient quantities.

1 It should be noted that other scrap categories exist (e.g. E1, E3…) which are not related to the vehicle life cycle (except for some parts from mechanical engineering). These categories will be mentioned in the report but not discussed further as they are not related to vehicle flat steel closed loop recycling, which is the focus and purpose of this study.

2 Copper is one of many other pollutants of steel scrap (e.g. Al, C, N, Cr, Ni, Sn, Si, S, P…) and other steriles. However, unlike other materials, Cu cannot be removed in steelmaking and might cause casting, surface quality, coating, welding problems etc.

As part of IMT's large-scale trial in 2024, nearly 300 ELVs were dismantled using an industrial process to manually remove copper-containing pollutants. The depolluted vehicle hulks were then shredded and tested in both a large-scale steel mill and laboratories to determine their suitability for high-quality automotive flat steel production.

Our findings indicate that by increasing and improving manual wiring removal during dismantling, the copper content in E40 scrap can be reduced to 0.09%, a significant improvement compared to the current 0.4% average in E40 from ELVs commercialized in Western Europe.[3] This reduction falls below the 0.15% threshold required for automotive-grade flat steel production,[4] making a closed-loop value chain possible. Furthermore, this quality improvement is economically viable, as revenues from recovered copper offset additional labor costs (considering French labor costs).

Based on these findings, we recommend establishing a new commercial standard, E40+, which accounts for improved shredded scrap quality, thereby increasing its market value and benefiting the entire value chain. This added value creation could also help limit the export of ELVs outside the EU, which poses multiple concerns, including safety issues and the loss of strategic materials critical for European industry resilience.

In light of ongoing discussions on a revised ELV Regulation, these results reinforce the ambition and feasibility of fostering closed-loop steel scrap recycling in the automotive sector. The IMT study provides technical and economic evidence on the importance of requiring or incentivizing copper removal at the dismantling or post-shredding stage. Establishing quantitative targets will be key to defining a new scrap classification that fosters value creation and fair distribution throughout the supply chain. Additionally, the regulation should include eco-design requirements for OEMs to facilitate the removal of copper wiring from ELVs.

This study, which focuses on the dismantling stage, will be complemented in 2025 by further trials at the shredding stage. These tests will evaluate the effectiveness of post-shredding technologies (advanced sorting technologies), particularly in ensuring high-quality control, which is essential for producing premium automotive steel.

3 DAEHN Katrin et al. (2017), Environmental Science & Technology, How Will Copper Contamination Constrain Future Global Steel Recycling?, https://www.researchgate.net/publication/316502506_How_Will_Copper_Contamination_Constrain_Future_Global_Steel_Recycling; ADEME, Deloitte, (2023) Etude du potentiel d'amélioration du recyclage des métaux en France, https://www.actu-environnement.com/media/pdf/news-43668-potentiel-amelioration-recyclage-metaux.pdf

4 "Average global scrap currently has a copper content of 0.15% and already exceeds the limit for a large share of high-end steel products", Material Economics (2020), Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminum, https://materialeconomics.com/node/15

KEY FINDINGS

◗ The Results have demonstrated the relevance of the project: **copper contamination of end-of-life vehicle steel scrap is a growing concern due to the continuous increase of electronic and digital features in cars**. This contamination is one of the main hurdles to the implementation of car-to-car closed loops, in particular for high quality automotive steel production using EAF. This subject remains poorly documented publicly given its complex financial stakes and despite being recognized by stakeholders along the recycling value chain. Such stakes encompass on one hand the distribution of financial and/or regulatory efforts to improve sorting of end-of-life waste streams and on the other one the competition to capture these operations' added value. This project thus strives to provide independent third-party involvement, instrumental to objectivize the technical and economical stakes and facilitate dialogue on triggers of value creation and a genuine circular economy of automotive steel scraps. It is crucial to **reconcile the various stakeholder's interests and redistribute the newly created value** of depolluted steel scrap and copper recovery through the approach demonstrated in this trial. In details, the project has shown that:

◗ **Manual (or manually assisted) dismantling operations**, using existing practices and facilities (at both the dismantler and shredder level), can produce **E40 steel scrap with a residual Cu content of less than 0.15%**[5] **or even less than 0.1%** (vs. > 0.25-0.4% in current E40 commercialized in western Europe[6]).

◗ The **quality of this post-consumer E40 scrap is sufficient to be considered as part of the raw material mix for the production of automotive high-grade flat steel in EAFs** in addition to virgin iron (as DRI, HBI or hot metal) pre-consumer scrap and other sources of post-consumer scrap, in very high proportions (up to 60% is possible for high-grade automotive steel)[7].

5 "Average global scrap currently has a copper content of 0.15% and already exceeds the limit for a large share of high-end steel products", Material Economics (2020), Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminum, https://materialeconomics.com/node/15

6 DAEHN Katrin et al. (2017), Environmental Science & Technology, How Will Copper Contamination Constrain Future Global Steel Recycling?, https://www.researchgate.net/publication/316502506_How_Will_Copper_Contamination_Constrain_Future_Global_Steel_Recycling; ADEME, Deloitte, (2023) Etude du potentiel d'amélioration du recyclage des métaux en France, https://www.actu-environnement.com/media/pdf/news-43668-potentiel-amelioration-recyclage-metaux.pdf

7 ICCT (2024) Which automakers are shifting to green steel? An analysis of steel supply chains and future commitments to fossil-free steel, https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf; Nucor. (2023), *2022 Recycled content averages for Nucor steel mill products*, https://assets.ctfassets.net/aax1cfbwhqog/7Ma2avTxQFdBEwFCITrHkC/cf43e0dc63ce91831b842a0e0f8c2fab/Recycled_Content_Letter_Mill_Products_RY2022.pdf

◗ The site where the trial was performed is representative of the current best dismantling practices in Europe (the site operates as a profitable dismantling facility that meets current regulatory requirements. However, in its daily operations, the site limits the copper wire extraction to easily removable components that guarantee a profit when sold for recycling). It is demonstrated that implementing a deeper copper removal process (maximizing the recovery of all visible copper wires during the dismantling process) yields promising economic results. **The additional value recovered through the sale of copper wires offsets the additional extra-cost due to in-depth wire extraction (considering both the LME prices for copper and the trading prices of the hulks).**

◗ This trial demonstrates that **the necessary conditions for increased circularity in the end-of-life sector are potentially met, both for the steel and copper,** the latter being a strategic metal for the transition. Its recovery and recycling are even more crucial as **the copper content in ELVs is expected to rise significantly in the coming decades. Without a better separation from steel scrap, the recycled steel quality will continue to decrease**.

◗ The trial demonstrated that one can generate, **at the dismantling stage, low copper content hulks with a higher potential economic value, and consequently, after shredding, an E40 steel scrap with higher quality and hence value than classic E40**. New revenues in the value chain can be generated from **the recovered copper and a better valorization of E40 steel scrap. This value will be created only if the generated added value is well and fairly redistributed to all the industrial stakeholders involved (dismantlers, shredders, steelmakers)**.

◗ The results of this project are promising. However, **additional tests and analyses would be beneficial to identify the optimal economic balance among the different extraction and sorting solutions proposed by the actors of the supply chain** (whether manual or automated). It will also be important to **assess the performance capacities** as well as the **efficiency of quality control**.

◗ **Incentivizing or mandating closed-loop recycling of ELV-derived materials to new vehicle production** (through a partial ELV-origin requirement for recycled steel content) **would primarily benefit copper recovery from ELVs**, and therefore partly tackle this persisting challenge.

KEY RECOMMENDATIONS

The following 6 recommendations are detailed in chapter IV (from page 33 of the report).

1. **Create a new high-quality steel scrap standard (E40+)** as a positive economic incentive to adopt and reward better practices on the ELV value chain and to ensure a fair added value distribution.

2. **Incentivize copper removal from ELVs in the new regulatory framework. Favoring a performance-based obligation** (by combining the efforts of dismantlers and shredders) rather than placing the obligation solely on one actor (in line with the current obligation for 85% mass recycling outlined by the current ELV Directive).

3. **Combine all demand boost policies** (including potential **mandatory recycled content for flat steel** in cars placed on EU market from 2030) to leverage the automotive industry as a lead market for decarbonized steel, **with significant local (made/processed in Europe) content quota requirements.**

4. **Increase the sharing of targeted strategic data** between OEMs and ATFs for a better end-of-life management and value creation (e.g. wire content and location), potentially through the Circularity Vehicle Passport.

5. **Improve eco-design practices** in particular regarding the wiring architecture and solution to facilitate disassembling and extraction.

6. **Further investigate the right balance and complementarity, in terms of quality control and cost/value, between deep-dismantling and shredding/post shredding** (automated or manual) solutions. This aspect, which may be country or region specific depending on the current ELV local treatment fabric, will be further investigated by IMT and its partner in 2025.

The first three recommendations which are directly connected to the trial results are further developed hereunder:

We recommend the **creation of an "E40+" commercial steel scrap standard** (and subsequently a "hulk+" standard), which would **guarantee a reduced level of residual copper contamination (<0.15% of residual copper)**. This improved E40 would allow increased incorporation of this high-quality scrap into the production of high-quality automotive flat steel.

The increased quality of E40+ and thus the extra-value created would lead to an **economic incentive** for all players of the end-of-life value chain to proceed to increased copper extraction and sorting. Indeed, a commercial standard provides both a **predictable and a commercial value to the E40+, and the added value can be distributed all along the value chain and spark commercial negotiations between the industrial players of the end-of-life and steel sector**. Consequently, it would also influence strategic orientations of the actors of the ELV value chain and ultimately motivate investments.

The market levers and tooling considered here above should be complemented by an EU regulatory framework incentivizing copper removal practices. **The new European ELV regulatory framework should incorporate a requirement for achieving a specific wire mass extraction ratio.** However, this provision should not dictate whether the extraction is to be performed exclusively by dismantlers or shredders. It should remain flexible, allowing for a combined approach of wire removal that mirrors the current method of recycling ratios contained in the ELV Directive, which applies to the entire vehicle mass

Alternatively, Annexe VII of the Regulation could contain an obligation to dismantle wires before shredding. However, since its implementation might potentially collide with a wide diversity of practices within the EU and control capacities could be limited, an alternative solution could be similar to the current minimum recycling ratio obligations of 85% included in the ELV Directive which applies to the total mass of the vehicle. Indeed, all necessary reporting elements are already set up, and such an obligation would bind the relationship between shredders and dismantlers since the target will need to be reached through a combination of both extraction rates.

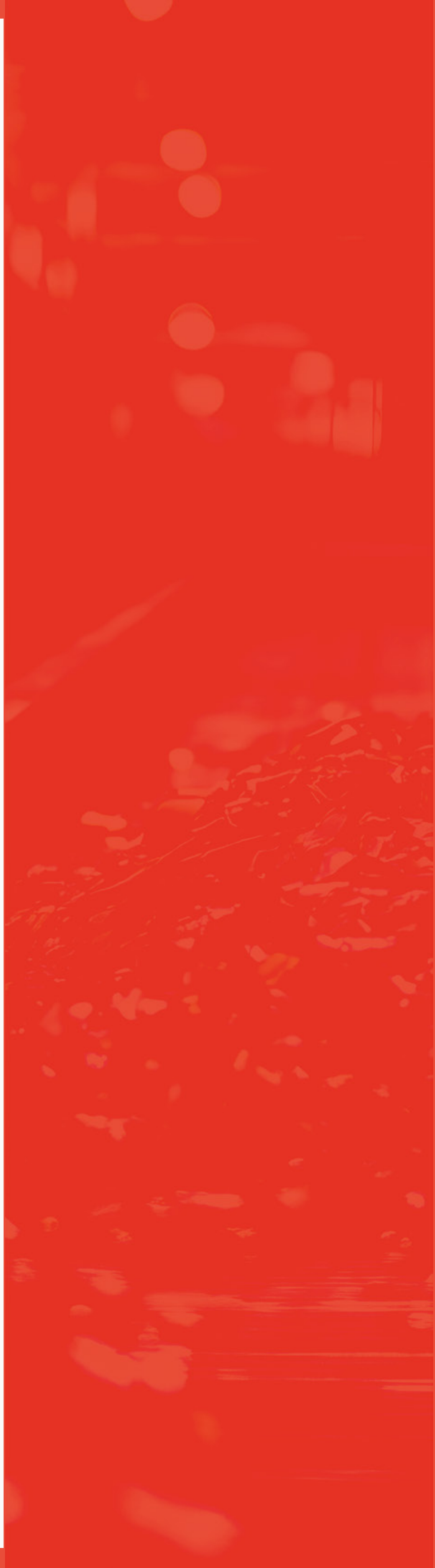
We suggest implementing this target no earlier than 2028. This timeline would provide Member States with **sufficient time to establish the necessary specific reporting and control procedures to meet this new requirement. These procedures could include audits, mass reporting and performance tests for shredders**, similar to those currently in place for the already existing 85% recycling target contained in the ELV Directive.

In order to create an efficient demand shock, the proposal of the ELV Regulation drafted by the European Commission includes a provision offering the possibility of implementing a **minimum recycled steel content**. The provision requires the Commission to evaluate the possibility for new cars entering the EU market after 2030 to contain a minimum amount of recycled steel.

This provision aims at providing a substantial market visibility for recycled steel demand increase, securing potential investment in the DRI-EAF route. Indeed, there is a **consensus in the EU to consider that the automotive industry should be the lead market for green steel production development in the EU.** Regarding the design of mandatory recycled contents, **we suggest progressive approach and the creation of separated target trajectories for flat steel and long steel.**

In addition to introducing minimum recycled content requirements for steel or other materials, we strongly advise **introducing local content requirements (LCR) or local content scoring, specifying that a substantial portion of recycled material must be sourced from EU-based ELV recycling industries to protect the competitiveness and resilience of the European automotive supply chain and particularly production sites based in the EU**.

Other options could lead to similar results but need to be considered within **a multi-material approach**. A potential approach could involve developing a methodology to calculate the **carbon footprint of steel products** or **establish green steel ratios**, provided a consensual definition of green steel has been determined. **This methodology could be part of a broader framework, similar to the "eco-score"** used in France to incentivize the purchase of EVs.



CONTEXT & CHALLENGES

Decarbonizing the automotive industry includes decarbonizing steel production

Emissions from the transport sector account for 23% of global energy-related CO_2 emissions, and 70% of direct transport emissions are due to road vehicles.[8] In the current context of climate change, decarbonizing the mobility and transport sector is crucial. As part of the commitment by the EU, the objective for mobility is to become GHG neutral by 2050. Alongside modal shift, electrification of transport (in particular of passenger cars, light commercial vehicles and trucks) is required to tackle road transport vehicle emissions.

However, for decarbonization to be effective, reducing tailpipe emissions through electrification must go hand in hand with a reduction of embedded emissions due to vehicle production.

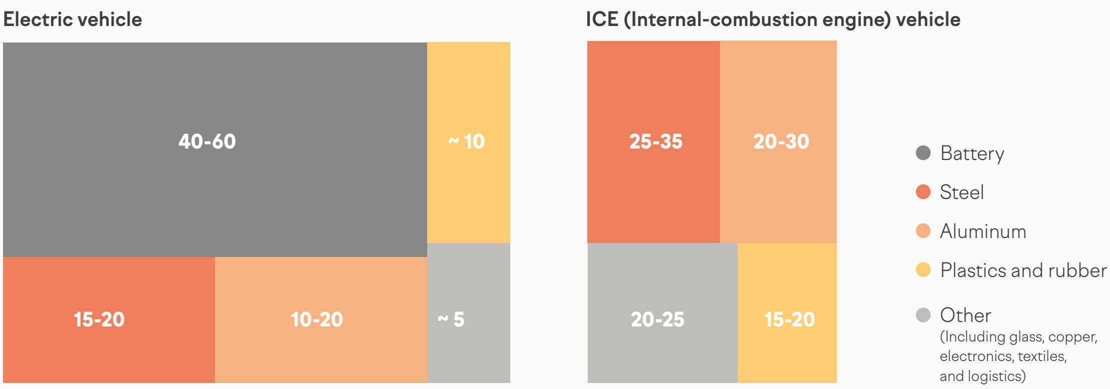
This study is dedicated to the challenge of managing decarbonized steel production with a focus on the car's life cycle to assess the contribution of end-of-life recycling to this ambition (**Figure 1**).

The European regulatory context is conducive to the study of decarbonization in the automotive steel industry at two levels. The EU aims to decarbonize its steel production, using regulatory incentives, obligations and protections, such as EU ETS and CBAM. Additionally, the ELV Regulation proposal will introduce increased circularity obligations and improved ELV treatment requirements, amending the ELV Directive that had been regulating the ELV management for over 20 years.

8 IPCC Working Group III (2022), Climate Change 2022 Mitigation of Climate Change (Sixth Assessment Report), doi: 10.1017/9781009157926.012

FIGURE 1. Typical upstream battery-electric-vehicle emissions (%)

Typical embedded emissions of an electric vehicle vs a combustion vehicle: steel is the second largest source of embedded emissions after the battery



Including all upstream emissions from raw material extraction to the OEM, including logistics.

Source: McKinsey & Company, 2023 (The race to decarbonize electric-vehicle batteries) https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

Steel use in the automotive industry

The automotive sector represented about 17% of steel consumption in the European Union in 2022 (23Mt).[9] In the EU, a typical passenger car currently uses an average of 800-900 kg of steel, making up approximately 50-66% of the vehicle mass, depending on its age, model, segment and powertrain type.[10] About 58% of the steel is used in the body[11] and 80% of the steel in the body consists of flat steel[12] and thus requires a very low copper contamination rate to meet the required high quality steel specifications set by the car makers. This flat steel produced in the EU is mainly produced through the BF-BOF route[13] and the steel scrap incorporation rate is limited (including due to this copper contamination issue) to a maximum of 15-20% (pre- and post-consumer scrap).[14] The post-consumer scrap use in the BF-BOF route is very low and represents only a few percent at maximum today.

It is acknowledged by all industrial stakeholders that the decarbonization of the steel industry will require progressive decommissioning of the BF-BOF route and the development of decarbonized DRI furnaces combined with EAFs. The switch to EAF will allow a larger incorporation of scrap quantities, provided that the quality of this scrap can drastically be improved. An increased introduction of steel scrap in EAFs using green H_2-DRI could contribute to the reduction of GHG emissions in steel production and limit the need for raw material's extraction. Moreover, from a resource supply standpoint, including some geostrategic autonomy issues, the development of a much larger circular steel usage (closed loop recycling and supply) is essential and included in the EU clean industry ambition plan.

9 World Steel Association (2023), Steel in automotive, https://worldsteel.org/steel-topics/steelmarkets/automotive/

10 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

11 Argonne National Laboratory, Center for Transportation (2022), Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model (2022 Excel), https://doi.org/10.11578/GREET-Excel-2022/ dc.20220908.1

12 Metals Consulting International (2024), Automotive steel weight analysis, https://www.steelonthenet.com/files/automotive.html

13 Xerfi (2022), La filière sidérurgique en France, https://www.xerfi.com/presentationetude/le-marche-de-la-siderurgie_MET12; ADEME, Deloitte, (2023) Etude du potentiel d'amélioration du recyclage des métaux en France, https://www.actu-environnement.com/media/pdf/news-43668-potentiel-amelioration-recyclage-metaux.pdf

14 Currently, scrap demand is adequately met by the availability of home and pre-consumer scrap. However, this situation is likely to evolve in the coming years due to the growing demand for steel scrap (in EAF) and finite volume of pre-consumer and home scrap available, EUROFER (2019), Low Carbon Roadmap, Pathways to a CO_2-neutral European Steel Industry, https://www.eurofer.eu/assets/Uploads/EUROFER-Low-Carbon-Roadmap-Pathways-to-a-CO_2-neutral-European-Steel-Industry.pdf

Current and future steel production route

Steel is mainly produced from mined iron ore, reduced at high temperatures for the production of various steel categories.

Worldwide, 1.9 billion tons of steel are produced yearly,[15] while global steel production makes up 7% of global GHG emissions and 11% of global CO_2 emissions.[16]

The traditional steelmaking process, also called primary steelmaking, reduces the iron ore at high temperatures through the addition of coal and oxygen in a blast-furnace (BF). The produced iron then enters a converter (BOF), to which up to 20% of steel scrap (mainly pre-consumer scraps, and a few variable percentages of post-consumer scrap) can be added for the production of crude steel. This crude steel is then processed in so-called secondary metallurgy to reach the required compositional characteristics.

The primary route of steel production is very GHG intensive, in particular due to the use of coal in the BF. The secondary route produces steel from steel scrap in Electric Arc Furnaces (EAF). To date in Europe, this route is mainly used for the production of long steel. A new technological route has appeared in recent years intended to reduce GHG emissions through the use of hydrogen as a reduction agent of iron ore in the solid state. This DRI technology is already used regionally with the injection of natural gas but has not yet been implemented on a large scale with hydrogen. This new H_2-DRI route reduces iron ore with hydrogen in a direct reduction plant. The produced DRI can then be melted to steel in an EAF (**Figure 2**).

Not only is the production of steel through the H_2-DRI-EAF route less GHG emitting thanks to the use

15 World Steel Association (2024), World Steel in Figures, https://worldsteel.org/data/world-steel-in-figures-2024/

16 Global Efficiency Intelligence (2022), Steel Climate Impact An International Benchmarking of Energy and CO_2 Intensities, https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities

FIGURE 2. **Production of high quality flat steel for the automotive industry**

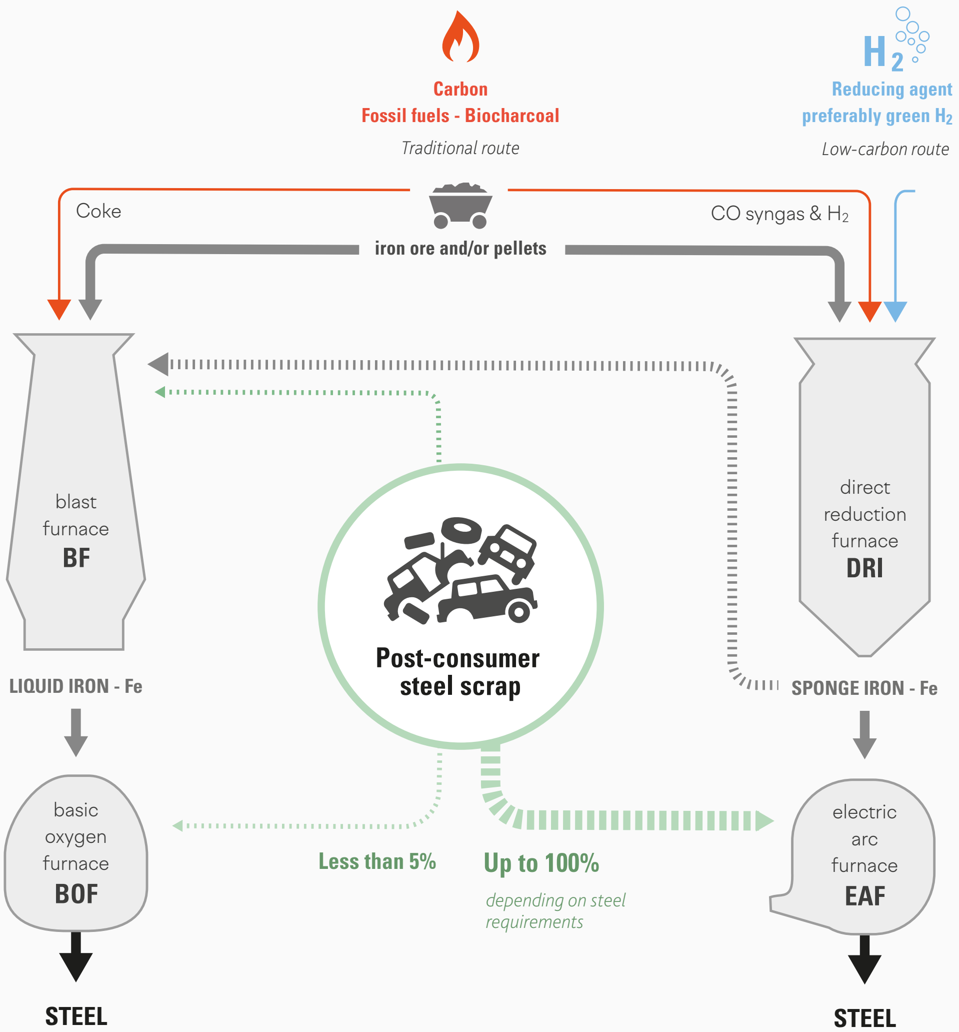
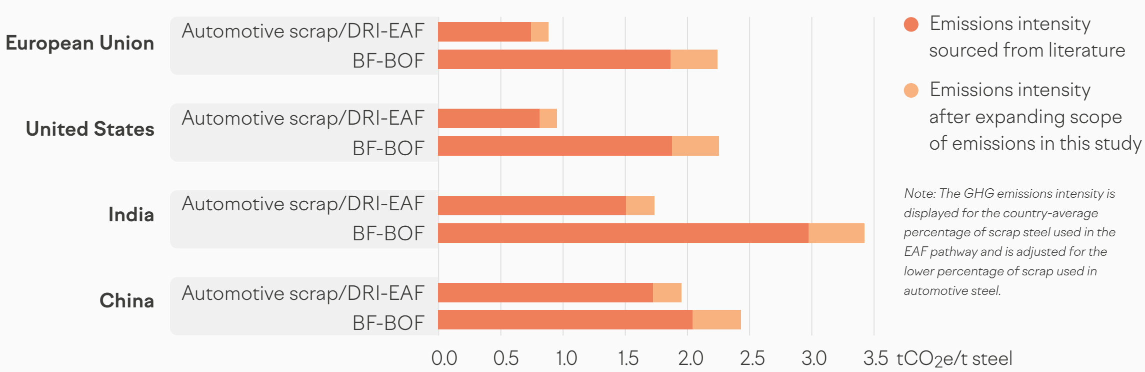


FIGURE 3. **GHG emissions intensity by process in major steel-producing countries and regions**

GHG emission intensities of the BF-BOF pathway and the DRI-EAF/scrap pathway for automotive and average non-automotive steel production in various regions, estimated based on the regional share of BF-BOF and EAF production capacity in each country or region, and country average emissions intensity. The emissions of automotive steel production are higher due to lower use of scrap compared to non-automotive average steel production (despite a maximum share of 60% scrap* assumed in automotive steel).



Source: ICCT 2024.

ICCT (2024), Which automakers are shifting to green steel? An analysis of steel supply chains and future commitments to fossil-free steel, https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf

Nucor. (2023), 2022 Recycled content averages for Nucor steel mill products, https://assets.ctfassets.net/aax1cfbwhqog/7Ma2avTxQFdBEwFCITrHkC/cf43e0dc63ce91831b842a0e0f8c2fab/Recycled_Content_Letter_Mill_Products_RY2022.pdf* of decarbonized electricity[17] (for H_2 electrolysis, energy supply of the DRI, EAF plants etc.), but the use of EAF allows the introduction of higher amounts of steel scrap. In comparison to the BF-BOF route, which can only accept up to 20% of steel scrap, an EAF can today theoretically accept up to 100% steel scrap (up to 60% for high grade steel production)[18] (Figure 3**). Indeed, steel is technically highly recyclable provided it is not polluted and depending on the quality and composition of the steel scrap, the type of alloys and the type of steel produced. The recycling of steel scrap for steel production could help decrease the carbon footprint of a steel product and limit the need to extract raw materials.[19]

In the current context of non-secured availability of green H_2, the sourcing of depolluted steel scraps to enter EAFs, including for the production of high-quality flat steel, provides increased flexibility to steel-makers, both short and long-term. This is a securing element for the strategic roadmap of the steel industry, which requires important and substantial investment decisions.

As the automotive sector is a key consumer of the steel industry and has particularly stringent requirements, successfully demonstrating the possibility of an increased recycled steel usage in this industry would encourage other sectors to follow suit.

In light of this and considering that the automotive industry will be a lead market for the development of near-zero steel production, we decided to study the challenges surrounding circularity in the automotive scope. Therefore, we set the focus on the required conditions for implementing closed-loop recycling from ELVs.

17 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

18 Nucor. (2023), 2022 Recycled content averages for Nucor steel mill products, https://assets.ctfassets.net/aax1cfbwhqog/7Ma2avTxQFdBEwFCITrHkC/cf43e0dc63ce91831b842a0e0f8c2fab/Recycled_Content_Letter_Mill_Products_RY2022.pdf; ICCT (2024), Which automakers are shifting to green steel? An analysis of steel supply chains and future commitments to fossil-free steel, https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf

19 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

End-of-life vehicle EU regulatory context

This study will focus on the mandatory recycled steel content contained in the current proposal of the ELV Regulation. We wish to contribute to the debate by developing an initial contribution on the decarbonization of steel through closed-loop steel production, and thus introduce into the debate the potential of using recycled ELV steel to reduce electric vehicle's embodied carbon footprint.

In order to understand the economic and commercial challenges related to deep-dismantling, it is important to examine the organization of the ELV value chain, including its traditional division of labor and value distribution.

The business of scrap metal from ELVs is organized around the collection, separation, depollution, treatment and transformation of scrap metal by a range of specialized players, with very diverse activities (**Figure 4**). Under the previous European ELV Directive, an end-of-life vehicle must first pass through a specific collection point, namely an Authorized Treatment Facility (ATF). The current ELV Directive contains some mandatory extraction stages and mandatory reuse or valorization targets of 95% (spare-parts and material, of which at least 85% of material recycling). However, the Directive does not specify how this target is to be achieved, and does not set any specific targets regarding the quality of the produced material.

Moreover, the dismantler's profession developed around the recovery of spare-parts, leaving low attention to the recovery of materials. This led to a rather counterproductive material recovery business, in which the price of the hulk sold to the shredder did not vary depending on its quality. Only the progressive increase of material value (other than the hulk in itself) led to increased material recovery. However, it remains a relatively recent phenomenon.

The shredder then reduces the hulks and, depending on the process, sorts the scrap through manual and automated mechanism, to eventually sell the produced E40 to steelmakers (more details are provided p. 30).

Current and future ELV regulatory context

Extract of the Directive 2000/53/EC on end-of-life vehicles (18 september 2000), Article 7 Reuse and recovery :

"2. Member States shall take the necessary measures to ensure that the following targets are attained by economic operators: [...] for all end-of life vehicles, the reuse and recovery shall be increased to a minimum of 95 % by an average weight per vehicle and year. Within the same time limit, the re-use and recycling shall be increased to a minimum of 85 % by an average weight per vehicle and year."

Extract of the Proposal for a Regulation on circularity requirements for vehicle design and on management of end-of-life vehicles

Policy option PO2 Use Recycled Content (preferred options):

"*N°2A: M10a – Empower the Commission to* ***set a mandatory recycled content target for steel****, including* ***calculation and verification rules****, based on a dedicated feasibility study*

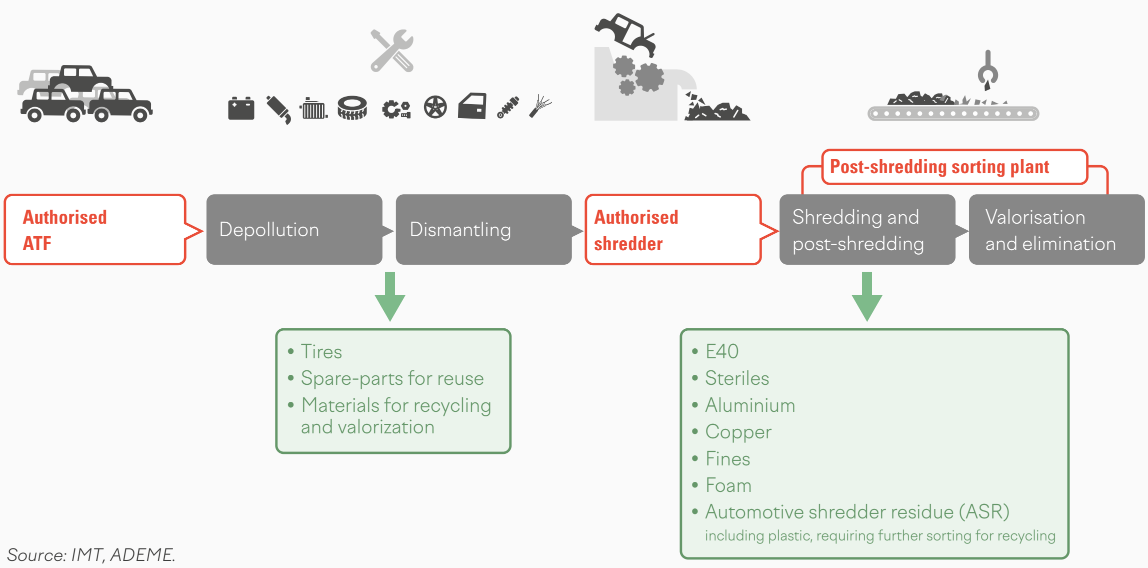
N°2B - M9b: ***Recycled plastics*** *content:* ***25%*** *in 2031 for newly type-approved vehicles only, of which 25% from closed loop production, calculation and verification rules*".

The ELV Directive, implemented in 2000, marked the EU's initial effort to establish a unified framework ensuring environmentally responsible treatment of ELVs. The Directive sets clear targets for ELVs and their components regarding reuse, recycling and recovery obligations. It aims to prevent and limit waste from ELVs and improve the environmental performance of all economic operators involved in the life-cycle of vehicles. It has often but not significantly been amended in the last decades. Its review launched in 2021 resulted in a proposal for a new Regulation in 2023, merging it with the type approval of vehicles for reusability, recyclability, and recoverability (3R type-approval Directive) to cover the entire lifecycle of a vehicle, from its design and market entry to its final treatment at the end-of-life stage.

Increasingly, European regulation tends to foster recycling and circularity in the automotive industry. While the current ELV Directive already imposes general average recycling rates (minimum 85% recycling and reuse ratio applying to the total mass of a vehicle), the upcoming ELV Regulation will set more specific recycling targets to foster material recycling, in particular through the obligation to increase the quantity of closed-loop recycled steel in new vehicles.

Indeed, the current Directive contains an obligation at Annex I to remove metal components containing copper at the dismantling stage if they are not segregated in the shredding process. However, the Directive does not define specific targets regarding the quantities of copper to be removed. The upcoming regulation should rectify this gap.

FIGURE 4. Explanatory schematic of the ELV value chain



Source: IMT, ADEME.

Copper contamination of the steel scrap

To increase the proportion of recycled steel from ELVs in new vehicle production, as considered in the discussion surrounding the ELV Regulation, it is essential to enhance scrap quality. Currently, E40 scrap from ELVs is mainly downcycled and for a significant part exported outside the EU for use in construction bars as long steel, as its quality is far from meeting the required standards for an extensive usage for the production of high-quality automotive flat steel. Indeed, high levels of contaminants, particularly copper, prevent this steel scrap from meeting the necessary mechanical and technical properties required by the automotive industry to be used as feedstock for the production of high-quality flat steel. Copper cannot be removed in steelmaking, unlike other elements (like Al, Zn, Si, S, P and non-metallics), and it can cause casting, surface quality, coating, and welding problems as well as become a potential unwanted hardening element (for soft drawing grades).

Historically, the scrap metal industry has dealt with this problem through a dilution strategy: rather than completely removing impurities, notably copper, the industry would mix contaminated scrap with cleaner materials and scraps, effectively reducing the concentration of pollutants to acceptable levels. This method has been sufficient for maintaining scrap quality - until now. Recent years have witnessed a significant uptick in copper content within ELVs, primarily driven by the increasing electronification of vehicles and the associated exponential growth of copper wires. This trend shows no signs of slowing down, on the contrary, presenting a growing concern for the future scrap quality. Indeed, the proportion of copper wires gradually increased in the last decades. These vehicles will gradually reach their end-of-life, and we can already estimate with certainty that this situation will continue to deteriorate.

If left unaddressed, the escalating copper levels could lead to a critical situation. Exceeding contamination thresholds would lead to ineffective dilution, as copper concentrations surpass manageable levels, and the quality degradation of the scrap could be such that even highly tolerant steel grades such as construction steel may become unattainable due to excessive copper content.

During the deep-dismantling project, focus was set on the removal of copper wires at the dismantling stage. Firstly, because copper wires represent a major contamination factor of E40. Secondly, because the manual removal of small rotors and motors is time consuming and thus costly. However, we are going to look at the removal of these parts in a new project in 2025, to determine the removability of these components at the shredding stage.

Current and future copper contamination

The copper content in vehicles has drastically increased over the last years: it has tripled over the last 20 years and will continue growing with the electrification of vehicles. While an ICE consumes approximately 20 kg of copper, a BEV needs around 80 kg of copper.[20] Meanwhile, the quality of copper ore is declining, and the average grades of mine concentrates are depleting, leading to higher extraction costs and environmental impact (**Figure 5**).

Copper in vehicles is present as copper wires and small motors and rotors. Indeed, copper is an excellent conductor, enabling the transfer of energy and information to different parts of the vehicle.

Different sizes of harnesses are available for different applications, as well as high-voltage and low-voltage harnesses, classified in various systems (AWG, mm^2...). Larger cable bundles are easier to remove compared to their thinner counterparts. The thinner bundles, typically measuring 0.35 to 0.5 millimeters, are more concealed and present greater challenges during extraction at the dismantling stage. The predominant bundles are the larger ones, primarily composed of main harnesses with their primary and secondary branches. When successfully removing these larger harness sections, approximately 75% of the total cable network can be removed.

The main aim of an efficient cable attachment technique is to ensure a secure fastening that effectively prevents unwanted movement and minimizes potential noise generation. Among the various cable attachment methods currently available, staple-based fasteners have emerged as the most preferred approach. These attachments are engineered with a strong emphasis on durability and structural integrity, which

20 International Copper Association (2017), The Electric Vehicle Market and Copper Demand, https://internationalcopper.org/wp-content/uploads/2017/06/2017.06-E-Mobility-Factsheet-1.pdf

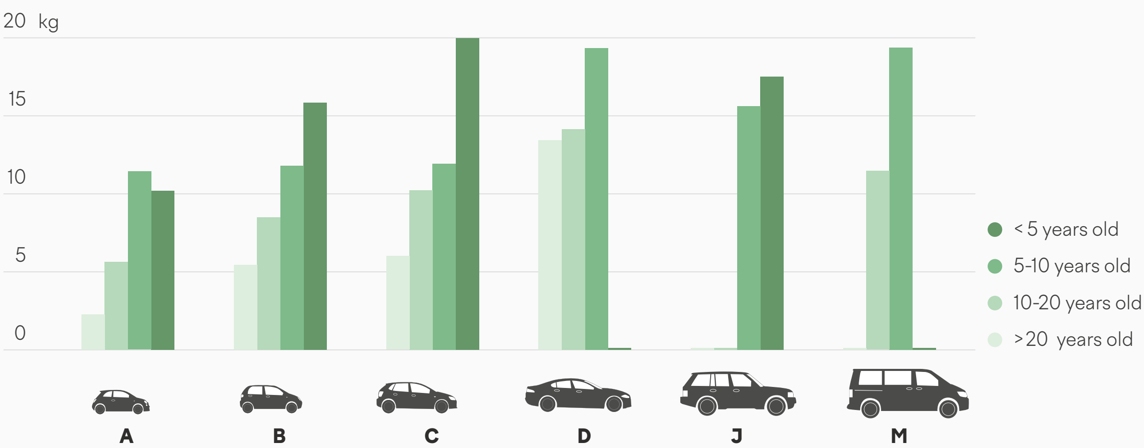
consequently makes them difficult to remove. Indeed, in the current design process, the priority is currently placed on creating a robust mounting solution rather than facilitating easy disassembly.
Other attachment methods already exist such as adhesive plates, used for the construction of certain licence-free vehicles, which have a shorter lifetime than classic passenger cars (around 10 years vs. 20 years[21]). Attaching the wires differently would require some R&D, but one could already think about attaching cables with hook-and-loop fasteners (Velcro® type) or other new methods, easily removable while remaining efficient and not leading to anticipated obsolescence.
It must also be noted that some small copper wires can already be replaced with aluminum wires and do not pollute the steel scrap. Nevertheless, due to its properties, aluminum will not replace all copper wires.

Increased copper removal of ELVs not only improves steel scrap quality, it also improves copper recycling rates, as an increasingly present metal in our vehicles. Copper is an essential material for the energy transition and as demand is growing, it is therefore crucial to recover and treat it properly.
Improving copper recycling is even more important that the concentration of copper mines around the world decreases[22] and that the availability of currently planned and financed mining projects may not meet anticipated copper demand over the decade 2020-2030. In that context of an imbalance between supply and demand, price pressures and shortages can be expected.[23]
Moreover, the concentration depletion of copper mines might increase the mining environmental footprint and operating costs. As a matter of example, the average extraction grade of copper ores could decrease by 1.5% to 3.7% a year over the upcoming decades, despite improved extraction and refining processes.[24]

21 ADEME (2023), Données Automobiles 2021, https://librairie.ademe.fr/

22 O.Vidal (2018), Ressources minérales, progrès technologique et croissance, https://doi.org/10.4000/temporalites.5677
23 WWF, IMT, EY (2023), Métaux critiques: l'impasse des SUV Quel scénario pour réussir la transition de nos mobilités ?, https://www.wwf.fr/sites/default/files/doc-2023-11/WWF_Rapport%20Me%CC%81taux%20Critiques_0911_HD.pdf
24 S. Northey, S. Mohr, G.M. Mudd, Z. Weng, D. Giurco (2014), Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining, https://doi.org/10.1016/j.resconrec.2013.10.005; WWF, IMT, EY (2023), Métaux critiques: l'impasse des SUV Quel scénario pour réussir la transition de nos mobilités ?, https://www.wwf.fr/sites/default/files/doc-2023-11/WWF_Rapport%20Me%CC%81taux%20Critiques_0911_HD.pdf

FIGURE 5. Evolution of the copper wires content in vehicles in kg per categorie



The data from the sample that has been analysed during this trial is representative of the current French and European ELV market.

Car categories help position each model in the automotive market. In Europe, categories are defined alphabetically:
A: Small city cars (e.g., Renault Twingo), B: Versatile city cars (e.g., Peugeot 208), C: Compact sedans (e.g., Renault Mégane),
D: Family sedans (e.g., Peugeot 408), E: Large executive sedans, F: Luxury limousines, J: SUV and pick-ups (e.g., Volkswagen Tiguan)
M: Multi-purpose-vehicle (e.g., Renault Scénic).

Source: INDRA, IMT.

Steel scrap standards

Various standards regulate the scrap metal business. One of the most widely recognized being the European Steel Scrap Specification [25], which categorizes scrap metal into various types, notably the pre- (E8) and the post-consumer (E40) scrap.[26] These standards provide a description of the required specifications, taking into account safety aspects, tolerance to residual elements and cleanliness of the scrap. This report addresses the potential of circular car material. Hence, it will focus mostly on steel scraps from body stamping (including in E8 category) and from end-of-life vehicle recycling (shredder scraps entering in E40 category). Other steel/cast scraps are generated from car production,[27] but their nature and oil content prevent them from being reused for the production of high quality flat steel.

Commercial standards: E8 and E40

E8

An important scrap standard used in automotive steel scrap production is E8. This scrap is clean of pollutants, as it is "pre-consumer" or "internal", i.e. a by-product of steel production or car manufacturing. E8 scrap is already efficiently recycled internally and reused in the steel production.

E40

E40 is a shredded steel scrap standard of post-consumer material. It should theoretically be free of metallic copper and other steriles.

When discussing the growing use of scrap in steel production and the need for enhanced recycling, a special focus is set on post-consumer steel, since pre-consumer steel is already efficiently recycled. Currently, E40 scrap from ELVs is mainly downcycled and partly exported outside the EU for use in construction bars for example.

Currently, ELV hulks are shredded and marketed as E40 scrap. The E40 standard stipulates a maximum of 0.4% steriles and 0.25% residual copper content. However, actual copper content in E40 scrap often exceeds these limits, averaging closer to 0.4%. This contamination is expected to drastically increase due to two interrelated factors.

Firstly, the cars produced today and in the years to come will contain far more copper than today's ELVs, which are on average 20 years old and contain few electronic copper-containing devices - already causing significant problems.

Secondly, current steel already contains a percentage of recycled steel and thus diluted copper. This contamination is likely to worsen incrementally over time and will reduce the dilution potential of the scrap. Without improved end-of-life management processes, future steel production faces the risk of reaching residual copper contents close to 0.8% in E40 scrap.

25 European Steel Scrap Specification is a standard developed by the European Ferrous Recovery & Recycling Federation (EFR) and the European Confederation of Iron and Steel Industries (EUROFER).

26 It should be noted that other scrap categories exist (e.g. E1, E3, EHRB, EHRM...) which are not related to the vehicle life cycle (except for some parts which can come from the mechanical engineering of certain parts). These categories will be mentioned in the report but not discussed further as they are not related to vehicle flat steel closed loop recycling, which is the focus and purpose of this study.

27 Notably from the mechanical engineering of engine parts.

Beyond Circular Economy : scrap use to secure the transition roadmap in EU and globally (terms of the debate)

This project aims at proving that an improvement of the ELV scrap quality through increased dismantling steps (so-called "deep-dismantling") can be reached while maintaining an interesting business case. This would encourage significantly closed-loop production of automotive steel, using the current momentum and even fostering the deployment of EAF based steelmaking and the increasing commitment of OEMs to develop their circularity index to reduce their environmental impact. The Project also allows us to investigate how much these new practices could increase the recovery of copper, which is a critical material for the energy transition.

Deep-dismantling might not be a new practice, nevertheless its development can be greatly encouraged by the current context of environmental transition and strategic autonomy. However, it is worth asking if both EU industry and global CO_2 emissions reduction could benefit from increased steel circularity in Europe. To answer this question, we have raised below key aspects of EU priorities and potential impacts of an increased development of closed loop circularity for non-EU countries importing EU-produced E40.

First, it is now acknowledged that the EU can no longer ignore the environmental benefits and/or the economic competitiveness its large "urban mine" of material (post-consumer wastes, composed notably of steel scrap but also copper and other critical materials) can provide. Hence, proper steel cycling without technical or economical value losses (steel scraps are currently mostly downcycled within EU or exported and copper content in ELV is very poorly recovered today) could reduce EU's dependency on imported raw materials and safeguard its material value chain. It could also reduce its dependency on the Forex exposure (all value chain being in Euro) thanks to increased control on flows and on the cost structure.

On the other hand, one can recognize that the access and usage of exported EU scrap by emerging economies (India, Turkey…) in their local production limits the use of primary raw materials, thus reducing their CO_2 emissions. This assumption should however be nuanced since exported EU scraps are usually used for the production of construction steel bars, which can accept contaminated steel scraps given their low-quality specification (in comparison with the flat steel we are considering to produce using decontaminated scrap in EU).

The relevance of the current project, aiming at using ELV scrap in a closed loop production inside the EU, could therefore be questioned from a global perspective or even from a strict GHG emission and climate approach: if the importing countries lack European scrap for their steel production, will they need to turn to an increased production of primary steel through the traditional BF-BOF route, which would de facto increase the GHG emissions and end up to be counterproductive?

This normative approach of a potential bouncing effect could only be relevant in the short term while steel consumption globally continues to rise intensively (global scrap availability is far from being sufficient to supply the global demand). In the next few decades however they might be less and less relevant when demand will reach its peak.

It remains important, when possible, to encourage a better distribution of the value creation with developing countries willing to decarbonize their own industry. Such a value distribution could, for example, take the form of a trade deal including exchange of green H_2-DRI produced by emerging countries on one hand and supply of European steel scraps to emerging economies on the other hand. Nevertheless, one must not forget that, in an increasingly fragmented world, European stakeholders will not easily give up control of a large part of their supply chain and neither will they give up their industrial legacy (companies, plants and workers). In that sense, the balance between global value redistribution, European strategic autonomy and the management of European legacy needs to be handled wisely.

We believe it remains rational and useful to initiate and support by all means the necessary heavy industrial transformation by investing as of now in low-carbon facilities (green H_2, DRI and EAF) in Europe and preserve this technical orientation in the long run.

One can imagine that a dual sourcing for EAFs (green H_2-DRI + decontaminated steel scraps) will evolve progressively to an increased H_2-DRI use, once this route has efficiently developed, notably thanks to increased availability of affordable green H_2. But in the short term, the access to decontaminated high-quality scrap is essential to secure the transition from BF-BOF to EAF route in the EU, as well as the crucial recovery of copper lost in ELV hulks.

In this context, and even more if the scrap quality is improved, European players will want to maintain their access to that European "urban mine" to be used as a lever to optimize primary steel production in DRI-EAF. Hence, it would be illusory to believe that these flows could be redirected for reallocation without considering these economic aspects.

For all these reasons, we consider that it is urgent to investigate the condition of a strong and competitive circular path within Europe.[28]

The decarbonization of the European industry and the development of recycling capacities could serve as a lead market for other countries and act as a source of industrial development model, while cleaned scraps will still remain available for export, should the need arise in emerging countries.

28 On that topic, more details can be found in the publication: IMT, Aligning decarbonization, circularity and competitiveness in Europe's automotive industry (2025) https://institut-mobilites-en-transition.org/en/publications/aligning-decarbonization-circularity-and-competitiveness-in-europes-automotive-industry/

APPROACHES & METHODOLOGY

Abbreviations and definitions

ADEME	The French agency for ecological transition, under the supervision of the Ministry for an Ecological Transition, Energy, Climate and Risk Prevention and the Ministry for Higher Education and Research
ATF	Authorized treatment facility
BF-BOF	Blast Furnace-Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism
Copper-containing residues	Material removed from the ELV, containing among other materials visible parts of copper (e.g. copper-wires, small rotors and stators…)
CSR	Corporate Social Responsibility of Companies
Downcycling	Recycling to make a product or a material of a lower value than the original item
DRI	Direct reduced iron
EAF	Electric Arc Furnace
ELV	End-of-life vehicle
ELV Directive	Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles
ELV Regulation	Proposal for a Regulation of the European Parliament and of the Council on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC
EU ETS	European Union Emissions Trading System
FAB	Material flow specific to INDRA Re-source's dismantling line, containing mainly ferrous materials and with a composition similar to the hulk.
GHG	Greenhouse gases
Hulk	Compacted car sent to a shredder following fluid extraction and parts removal
ICE	Internal Combustion Engine
IMT	Institut des Mobilités en transitions / Institute Mobility in transition
LME	London Metal Exchange
OEM	Original Equipment Manufacturer
PST	Post-shredding technologies
Wire	Copper-wire, composed of about 40-60% of copper and plastic casing

Project description & purpose

The trial in short

The scope of the trial and associated partners are presented **Figure 6**.

As part of the study, we:

- indentified the various stages of conventional dismantling and industrial dismantling at Re-source (INDRA) added targeted in-depth dismantling steps (deep-dismantling) at Re-source to recover more copper wires[29]
- shredded the deeply dismantled hulks as a batch in a shredder representative of the French average, without any advanced PST stages, to recover the improved steel scrap.

We then:

- analyzed the additional time spent by operators on each ELV for the matter of our project
- identified the quantity and quality of the additional material recovered by INDRA that is not sent to the shredder (copper, glass…)
- identified the positive and negative value of this additional material recovered
- calculated the delta of time spent/cost/material gain
- analyzed the quality of the recovered improved scrap in an independent laboratory, at ArcelorMittal's R&D laboratory and large scale at a steel mill to produce flat steel coils
- provided recommendations on the improvement of E40 quality.

Why focus on dismantling for this trial?

The current project involves taking the dismantling of ELVs one step further than usual, in order to recover more pollutants and determine whether the quality of the scrap recovered can be improved by dismantling alone and if it can result in an interesting business case. For this first project step, we decided to focus solely on deep-dismantling and not on advanced PST. However, this trial will be supplemented in a second stage in 2025 by additional PST trials, to determine the best available practices for increased scrap quality (**Figure 7**).

29 Another trial was conducted in parallel to our project at INDRA Re-source and involved removing the glass of the ELVs. This had no significant impact on the results of our trial, apart from a lower global hulk weight, that was taken into account for the analysis.

Improving the scrap quality: deep-dismantling or PST? Advantages and disadvantages

The quality of the scrap can be improved at two stages, either at the ATF through in-depth manual extraction of key polluting parts (deep-dismantling), or at the shredding plant though advanced PST. Both techniques are considered to be complementary, since both have their strengths and weaknesses. However, for the matter of differentiated and precise analysis, it is necessary to separate both techniques to identify their impacts and benefits.

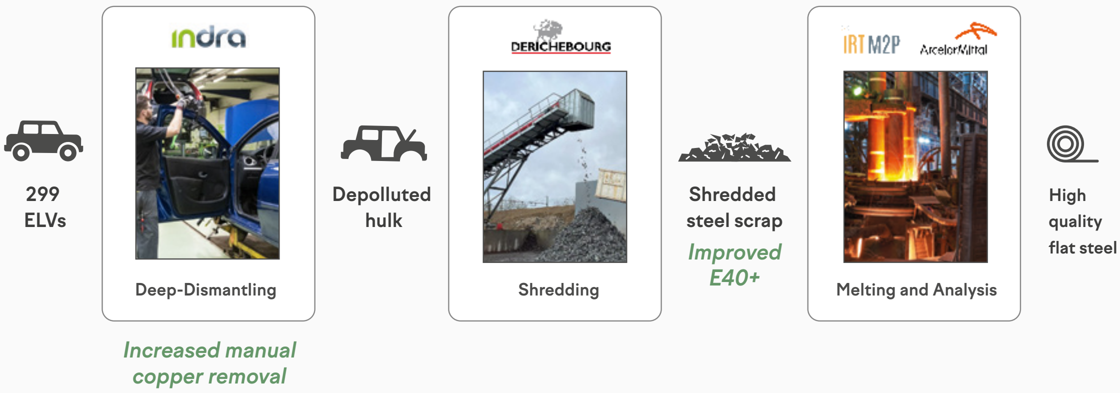
Deep-dismantling has the advantage of requiring low additional investment and can be implemented quickly and simply in already existing facilities. The polluting materials and parts can be precisely targeted and allow high agility thanks to the presence of human operators. Additionally, the large distribution of ATFs allows low logistic costs and emissions due to transport, since ATFs are usually the first owners of ELVs.

However, deep-dismantling in ATFs can be very variable due to the wide diversity of current practices, which leads notably to unsteadiness of quality control. Furthermore, the current business model of ATFs encourages the selling of non-valuable material in the vehicle hulk, since today the hulk value is estimated by weight and not by quality.

In contrast, PSTs allow working in batches, which facilitates quality control and stability, a crucial criteria for steelmakers. Due to their mode of operation, PSTs make it easier to define quality standards.

However, PSTs require important CAPEX and rely on long term investment, which leads to slower implementation as well as to a limited geographical expansion of these PST. Hence, equipping limited sites with advanced PSTs leads to increased logistics, leading to higher transport related emissions and costs. As a matter of example, France relies on about 50 shredders, with heterogeneous performance levels (see Annexes).

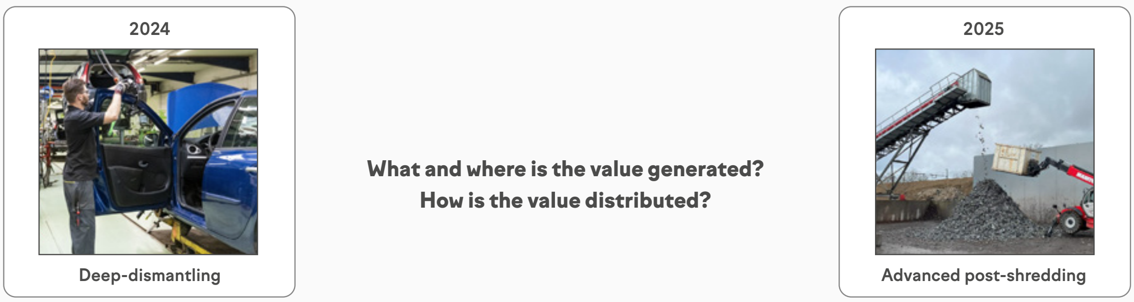
FIGURE 6. **The potential of deep-dismantling to decarbonize automotive steel using increased end-of-life vehicles (ELV) steel scraps in electric arc furnaces (EAF)**



Source: INDRA, IMT.

FIGURE 7. **Challenges and scopes of copper removal at each step of the ELV treatment process**

The subject of deep-dismantling has been addressed in 2024 while the subject of advanced post-shredding is expected to be addressed in 2025



Deep-dismantling (2024)

\+

- Low additional investment
- Simple and quick implementation
- Agile and targeted
- First owner privilege

\-

- Diversity of current practices
- Quality control (steady)
- Today paid for non valuable materials (Hulk value on weight)

Advanced post-shredding (2025)

\+

- Batches possible
- Quality stability : easier to pilot
- Quality standards easier to define

\-

- Potentially: higher CAPEX, long term investment and slower implementation?
- Low cost solutions to investigate
- Logistic costs if few shredding sites equipped only

Source: IMT.

Collaborations

In the framework of this full-scale project, IMT collaborated with various economic players of the ELV-value chain and notably with steel producers. The processes implemented are similar to the daily operations on the industrial sites involved in the project to represent current field conditions. Only limited additional operations targeting material recovery were added for the purpose of the trial in order to produce figures strictly comparable to usual practices. In order to fulfil these very important requirements, we exchanged thoroughly with the partners involved as well as with OEMs.

Technical partnership

INDRA Automotive recycling - Re-source

INDRA Automotive recycling provided access to its regular dismantling site Re-source (Romorantin, France), as well as some engineering support for the definition of the samples and the protocols. Following the completion of the trial, they also provided figures and data to proceed to a comprehensive technical and economic analysis.

INDRA was chosen within a wide variety of dismantlers for its advanced expertise in end-of-life vehicle management as well as for its advanced dismantling process at Re-source, the site that has been used for the trial. INDRA is also managing the largest dismantler network in France (about 300 independent facilities to fulfill OEM's regulatory obligations according to the current EVL directive) to which it provides ELV volumes (national contracts near insurance companies and OEM retail network) as well as engineering services and second-hand spare parts market place.

INDRA's dismantling site Re-source in Romorantin is representative of the most modern dismantling sites, implementing best available techniques for an efficient dismantling in line with the ELV Directive. It represents a realistic and viable dismantling facility.

It also presents the advantage of being managed very precisely and in a well-documented manner to fulfill the needs of INDRA's engineering division located on the same site (traceability, time measure, weight and all relevant data for our study are followed carefully for years at this site). It therefore represents an ideal experimental site for the project.

The process has been improved for the trial with additional dismantling steps on elements that have so far gone unaddressed, despite already working beyond current industry standards.

Indeed, Re-source is one of the players which has gone deep in extracting the copper wires for economic reasons. For the matter of the trial however, we wished to go further and extract the harder to access wires and determine if there is a positive business case.

Thus, INDRA Re-source added some specific steps to its classic dismantling line to remove additional parts and materials to reduce the presence of copper in the hulk, the idea being to determine the limits of economic profitability of additional copper recovery.

It is interesting to notice that at INDRA Re-source, like at the wide majority of dismantlers, the engine block is always valorised, as a spare part or as material.

DERICHEBOURG ENVIRONNEMENT

Derichebourg Group is listed in the Paris stock market but controlled and managed by the DERICHEBOURG family. The group was founded in 1956, operating in 13 countries, mainly in Europe. In 2024, the Group produced above 5 million tons of recycled metals (steel, copper, aluminium, brass, stainless steel, zinc, etc.), backed by a dense territorial network of 280 collection and recycling facilities.

Derichebourg Environnement has historical expertise in the collection, recycling and recovery of materials and waste, in particular in the recycling and sorting of ferrous and non-ferrous materials, including notably the shredding of ELVs.

Derichebourg's recycling plant in Athis-Mons was chosen because it is representative of an average French recycling plant, that si to say a shredder, without particularly advanced sorting technologies but with the possibility to vary the amount of operators removing copper at the end of the shredding process and work in batches.

Derichebourg is capable of working in batches and to adapt its shredding process to the trial as well as to provide a clean shredder, required for accurate analysis.

ARCELORMITTAL

ArcelorMittal is one of the world's leading integrated steel and mining companies with a presence in 60 countries and primary steelmaking operations in 15 countries. It is the largest steel producer in Europe, among the largest in the Americas, and has a growing presence in Asia through its joint venture AM/NS In-

dia. ArcelorMittal sells its products to a diverse range of customers including the automotive, engineering, construction and machinery industries.
Like other EU steel producers, ArcelorMittal has developed a decarbonization strategy that includes an increased use of steel scrap as well as the development of the DRI-EAF production route.
We chose to cooperate with ArcelorMittal to carry out large-scale trials because of their importance in Europe regarding the production of steel for the automotive industry and their expertise in the use of steel scrap. Their ability to reproduce the conditions of an EAF in the BF-BOF route for the production of high-quality steel with increased levels of scrap and their various analysis capabilities at different scales (notably in the R&D laboratory) were valuable for our trial.

IRT M2P

The Institute for Technological Research into Materials, Metallurgy and Processes (IRT M2P) is an independent laboratory based in Uckange (France) with technical expertise and equipment in the field of metallic and composite materials. The IRT M2P has among others a strong expertise in the field of analysis and characterization of scrap for the production of steel, working for R&D projects in collaboration with industrial actors. For the matter of this study, IRT M2P proceeded to the sample's collection, to the manual sorting and analysis of the sample as well as to the melting and chemical analysis of the produced steel.

Other parties involved in the curse of the project

To ensure the entire value chain was integrated into the project, it was essential to engage OEMs from the outset. BMW and Renault, as two main European automobile manufacturers, engaged in discussion with IMT from the very beginning of the project on a regular basis to share data and feedback. These discussions were important to understand the challenges and strategy the OEMs follow regarding the incorporation of recycled content in their vehicles, but also at the construction stage of the vehicles as it is important to capture a circular vision of the industry.
Over the course of the project, IMT exchanged with additional experts and parties, for example with the French Society of Automotive Engineers (SIA), an association that brings together specialists of the automotive industry and whose goal is to encourage the development and knowledge sharing in France for the mobility sector as well as with the supplier MagnaSteyr, an automobile manufacturer that engineers, develops and assembles automobiles for other companies.
We also engaged with the Plateforme Automobile (PFA), the Verband der Automobilindustrie (VDA), the German Ministry of Industry and Climate Action (Ad-hoc-Arbeitsgruppe Dekarbonisierung automobiler Wertschöpfungsketten) and shared our preliminary results with various experts, including other shredders. These exchanges enabled us to gain a better understanding of the technical challenges faced with increased use of scrap metal and its impact on vehicle construction, technical and economic constraints and opportunities, as well as potential eco-design practices notably regarding copper wires.

Scope of the study

This study is primarily intended to contribute to the debate surrounding the improvement of steel scrap quality for a closed loop use in the automotive industry and aims to provide data and recommendations to institutional decision makers as well as to the various industrial stakeholders, in the framework of the ongoing discussion regarding the future of the ELV Regulation. The idea developed by this study is not new, but the context has evolved. The ELV Regulation under discussion is likely to set mandatory recycled content targets for various materials including possibly steel, whose ambition needs to be objectivized and challenged regarding its technical and economic aspects.
The car park data provided in this report are representative of the French market but are also considered to be sufficiently representative of western Europe situation to draw conclusions and recommendations that remain valid at EU level.
Indeed, the French ELV treatment sector stands out from other European countries by its scale, processing around 1.3 million ELVs per year through 1736 authorized ATFs and 60 shredders, which represents 26% of ELVs officially managed in the EU. This substantial volume makes France an ideal focus for in-depth research and development in ELV management practices.[30] Our

30 Eurostat (2024), End-of-life vehicles by waste management operations, https://doi.org/10.2908/ENV_WASELV

focus will be set on the official and authorized ELV processing route, though we are aware that a significant number of ELVs are treated outside regulatory compliance.

The financial data provided in the report are also French market based.[31] This conversely can hardly be considered as representative of the entire EU situation. Some of the findings related to the economy of the end-of-life business require to be confronted to each Member State specific market.

Project timeline

The 299 ELVs used for the trial were deeply dismantled between February and April 2024 at INDRA's dismantling facility Re-source in Romorantin (France).

The shredding process took place in Athis-Mons (France), at Derichebourg Environnement's facility at the beginning of April, and lasted for half a day.

The large-scale trial took place at ArcelorMittal's steel mill in Ghent (Belgium) in July 2024 and produced two coils of steel in two heats and a laboratory analysis took place in December 2024 at their R&D Center in Maizières-lès-Metz (France).

The laboratory analysis took place in December 2024 at IRT M2P in Metz (France).

Analysis method

The analyses of this report were carried out at different stages of the project. (**Figure 8**).

At the dismantling stage at INDRA Re-source, we studied in detail the dismantling steps, costs and additionally recovered materials (apart from the steel scrap) by cross-referencing the trial data with INDRA's internal data.

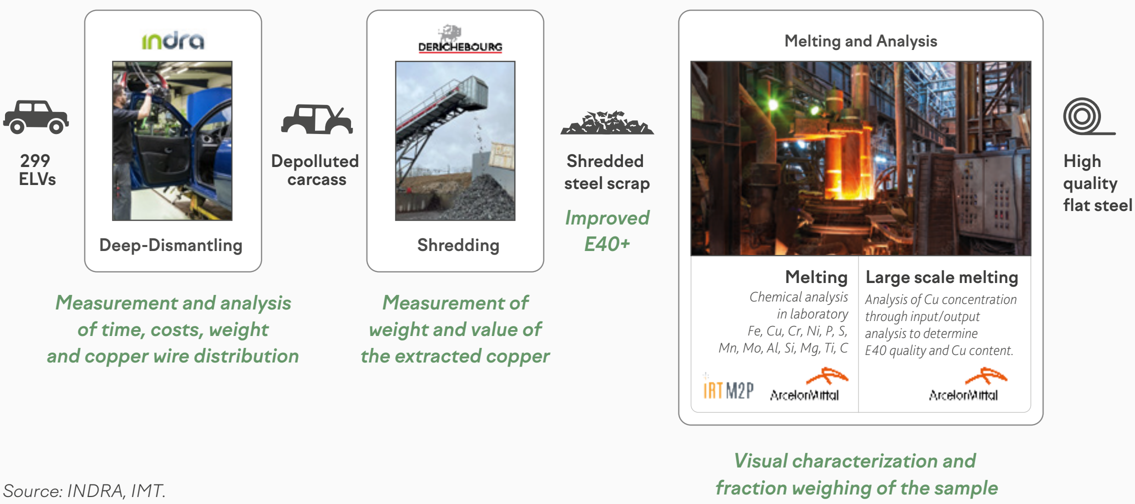
We then combined that information with data provided from the shredder, including notably the volumes of material recovered during the process, in comparison with data from the usual shredding process.

We analyzed the quality of our scrap at the IRT M2P laboratory. The residual copper-containing material was sorted manually and melted down in two stages. First, the scrap without the separated copper-containing material was melted down for an initial chemical analysis, before adding the copper-containing material to the melt to determine the exact chemical composition of our trial's scrap.

Finally, at a third analysis stage at a steel mill of ArcelorMittal, the trial's scrap was used in two heats for the production of two high quality steel coils. The quality of the produced steel was chemically analyzed. The scrap has also been analyzed in their R&D laboratory.

31 Since 2005, ADEME has been monitoring the ELV sector through the creation of the ELV Observatory to track the performances of the ELV sector. The observatory collects data on the marketing of new vehicles in France and the treatment of ELVs to monitor the industry's performance in terms of reuse, recycling and recovery of ELVs. These data are produced by French vehicle manufacturers, ATFs and shredders, shared on the platform SYDEREP. This study is based on the report 2021. In 2021, 1549 out of 1736 ATFs shared their data. Based on an analysis of this data, ADEME annually publishes a report on the ELV sector in France, ADEME, Automobiles Données 2021, https://librairie.ademe.fr/.

FIGURE 8. Overview of the different measures and analyses in the scope of the study



Source: INDRA, IMT.

TRIAL ANALYSIS & RESULTS OF THE STUDY

Common practices in the French ELV dismantling industry

The ecosystem of dismantlers in France (and in Europe) is highly disparate and often artisanal, since it was historically built around small scrap yards focused on the removal of steel scrap or spare parts. Thus, the extraction capacities and business models of this ecosystem are very diverse and more industrialized dismantlers such as Re-source by INDRA have better extraction capacities than average French dismantlers according to ADEME. Depending on their commercial strategy, dismantlers can choose to focus primarily on selling spare parts for the reuse market or generate additional revenue by recovering and sorting specific materials, which are then valorized separately from the hulk..

Despite the large variety of practices, the ELV Directive does set out certain obligations for ELV management. When a vehicle arrives at an ATF, it must be depolluted according to the procedure laid down in the Directive, which requires the removal of certain fluids (oils, coolant, brake fluid, air conditioning fluid) and parts (such as tires, batteries, catalytic converters, polluting materials containing lead, mercury, or certain chemicals). Dismantlers must also remove some materials to achieve the vehicle recycling and valorization targets contained in the Directive (see chapter *ELV EU regulatory context*). Depending on the existence of suitable valorization channels and an attractive market value, other parts and materials can be removed too. In terms of re-use, for example, certain parts such as internal combustion engines can represent a large part of the business model of certain dismantlers, while in terms of materials, the recycling of aluminium, polypropylene and copper has also partly been developed.

However, most dismantlers still leave several parts and materials in the hulk, driven by economic considerations. Indeed, leaving some materials in the vehicle can be more profitable than their removal, especially if the value of the extracted material is lower than their sale price as a hulk. Additionally, lack of manpower or space may discourage dismantlers from proceeding to deeper extraction operations.

As a result, the quantities of non-ferrous materials remaining in the hulk are significant and will only be partially extracted at the shredding stage following magnetic sorting and eddy current. Combined with the ever-increasing levels of pollutants content such as copper in vehicles E40, steel scrap quality is declining. The average residual wire rate in hulks sent to shredders in France today is of 86%. The objective of our project is to estimate how much the currently poor environmental and economic performance could be improved, and how increasing scrap quality - thereby preserving economic value - could motivate actors in the recycling value chain.

For the purpose of the trial, we chose to work with the industrial dismantling line of Re-source by INDRA, adding some specific extraction actions to remove more copper wires. In our analysis, the technical and economic elements provided correspond to the delta between (1) the current dismantling process operated at Re-source, which has been defined to optimize net value creation (material extraction and sorting targeting only the most accessible and profitable material) in the current business context (the hulk is sold to shredders at a price per kilogram, regardless of its actual material composition or value) and (2) the objectives we have set in this project which aim at maximizing the copper wires and electric engines removal, regardless of the labor cost a priori, in order to measure the quality increase and related cost or value.

Deep-dismantling trial

A classic Re-source dismantling process lasts for 2h15 on average. After having recovered the fluids and other mandatory parts such as the rears and catalytic converter, the operators systematically remove the powertrain, plastics (polypropylene of the front shock absorbers trims…), as well as some of the wiring harnesses. About 15 min of labor are dedicated to the removal of copper wires (mainly located in the engine, the engine bay and the dashboard). Certain body parts such as the front doors can be removed and be sold as a spare part.[32] Removal is carried out manually, with adapted tools supporting the operators, notably in certain force-intensive gestures or to access certain hardly accessible areas.

Usually Re-source extracts in average 5.54 kg out of 12.13 kg of copper wires per ELV for recycling, which represents about 45% of the total wires found in an ELV. Additionally, at Re-source, 1.87 kg of wires are removed from the hulk through the sale of second-hand spare parts (e.g wires remaining in a door…), and 0.67 kg are removed in another steel scrap flow (FAB). Once exiting a regular Re-source process, a car hulk thus contains 4.05 kg residual copper wires, which represents about 33% of the total wires found in an ELV (**Figure 9**).

Representativity of the ELV sample

For the matter of the trial, 299 ELVs representative of the French car fleet were deeply dismantled. To respect the representativity of the French car fleet, 25 different brands and about 100 different models, from variable age (average: 18 years) were used in the trial. We categorized these ELVs into model and age, in order to provide an accurate analysis, applicable to ELVs exiting the fleet in the next decades (**Figure 10**). Many of the vehicles used for the trial are accident vehicles. Thus, some ELVs are more recent than disposed ELVs due to their age and mileage. What is more, most vehicles in the trial are ICEs. The sample is therefore representative of the type of ELVs that will be exiting the French car fleet in the years to come and very close to the current average existing age (19 years according to ADEME data[33]).

The initial total mass of ELVs entering the ATF was 351 T. The average mass of one ELV entering the trial was 1175 kg, from which 609 kg were recovered by the dismantler and 566 kg were sent to the shredder. The total mass of the trial entering the shredder was of 174.44 T.[34]

We calculated the theoretical initial copper wire content in the ELV samples. The real theoretical mass of wires in an ELV of our sample is 12.13 kg (calculated based on the sample distribution using INDRA's database, including average copper wire content per model and age — more details are provided in the Annexes). We also identified their locations to ensure an efficient removal process. These wires are notably found in the dashboard, vehicle cabin, doors and seats, as schematically provided in the diagram below (**Figure 11**).

The site's usual wire dismantling operations are cost effective. Through this trial, we have tried to determine which E40 quality level can be achieved through maximal dismantling operations while maintaining their regular operational means. Additionally, we have determined the additional costs of these deep-dismantling operations.

Re-source's engineering team provided us with the figures: operators spent in total 7 min additional manual work time on each ELV - in comparison to the site's regular process to maximize the copper recovery.[35] The operators mainly focused on removing additional wires at the rear of the vehicle.

During the deep-dismantling process, the operators removed an additional 1.62 kg of wires, leading to a total of 7.16 kg of removed wires for recycling (about 60% of the initial total wires in an ELV). The copper wires content left in the hulk sent to the shredder is of 2.43 kg (20% of the initial total wires in an ELV). The average weight of an ELV exiting our dismantling process is of 566 kg[36].

32 These parts can also be sold as material in the "FAB" stream, which is not sold with the hulk to the shredder for process and logistical reasons. This specific flow, referred here as "FAB", consists mainly of ferrous materials and has a similar composition than the hulk. It is a side-specificity of Re-source, for process and logistical reasons.

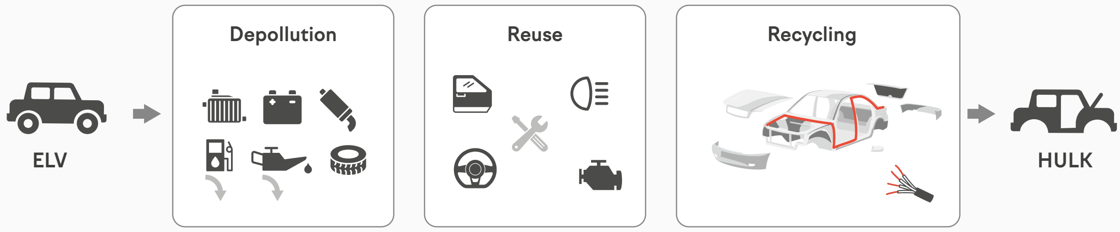
33 ADEME (2023), Données Automobiles 2021, https://librairie.ademe.fr/

34 In addition to the depolluted hulks, 5 tons (16.7kg/ELV) of the "FAB" flow containing almost pure steel scrap were sent to the shredder, since it consisted mainly of ferrous materials and had a similar composition to the hulk. These parts were mainly composed of front shock absorbers, motor cradles and exhaust lines.

35 It must be noted that the additional dismantling time for the removal of copper wires has not yet been industrialized as a process and might be optimizable.

36 As mentioned above, the vehicle's glass was also removed for the matter of another project led by INDRA and St Gobain thus leading to a lower hulk weight than usual (a total of 5812kg were recovered, meaning 19.44kg/ELV).

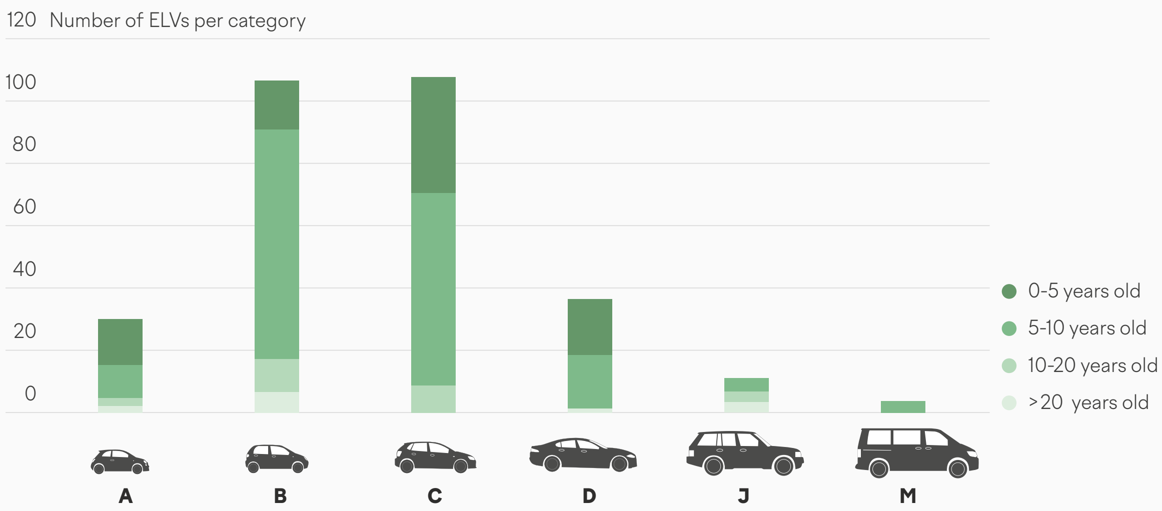
FIGURE 9. Regular compliant and profitable dismantling process at INDRA Re-source



On Re-source's dismantling line, once the ELV has been analyzed to determine the parts and materials to be removed depending on their condition and the market's demand, the vehicle is depolluted, and operators extract the spare parts and other components containing valuable materials for sale. The different material flows as well as the vehicle hulk are then sold to other actors of the ELV value chain.

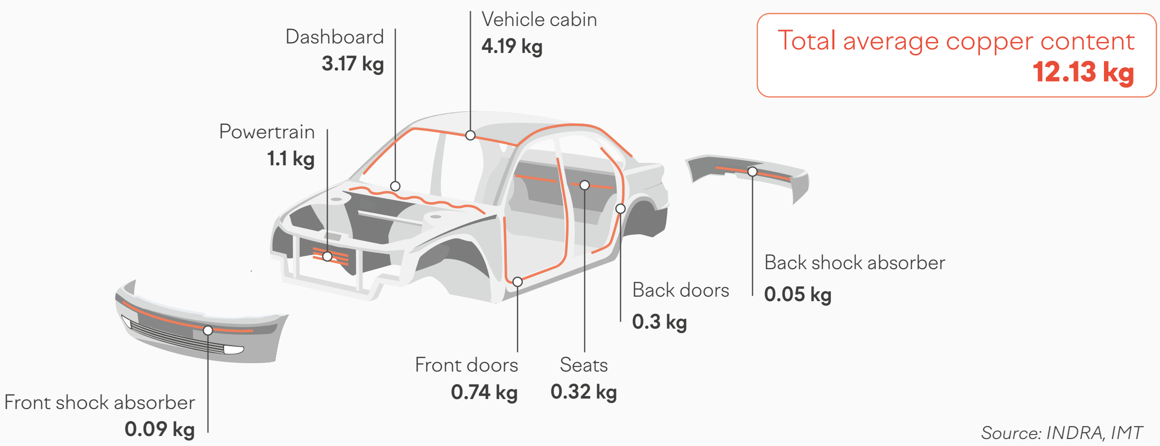
Source: INDRA, IMT.

FIGURE 10. Sample of vehicles tested during the trial



Source: INDRA, IMT

FIGURE 11. Repartition of copper wires in an ELV



Source: INDRA, IMT

Deep-dismantling enabled to lower the content of copper wires remaining in the hulk sent to the shredder from 33% (baseline process at Re-source)[37] to 20% wires in the deep-dismantling process. Compared to a French average dismantler, with an average residual copper wire content of 86% remaining in the hulk, deep-dismantling provided a reduction of 77% of residual copper wires (**Figure 12**).

The additional deep-dismantling operations are almost economically neutral. Indeed, the labor time spent for the matter of the deep-dismantling process is not-significant in terms of costs in comparison to the baseline process of Re-source. Thus, the recovery of the 7.16 kg **copper wires per ELV compensates the additional labor cost in terms of value. The deep-dismantling operation is self-financing in this trial. We can assume that these results will be similar or even better in European countries in which the labor costs are lower than in France (notably in southern and eastern European countries).[38]** (See **Figure 13**).

During this trial, the total difference of the net income[39] is only of 0.34€/ELV for a total net income of 137.12€ in a baseline Re-source process (**Table 1**). This result is based on prices to date of the trial (March 2024 - **Table 2**).

We have confirmed that the **market fluctuation of the hulk and copper prices remain insignificant when conducting a sensitivity study**. The difference between the economic balance of regular dismantling and deep-dismantling at Re-source remains minimal regarding the price variations and does not affect the potential of an interesting business case for improved copper dismantling.

37 Classic day-to-day profitable dismantling process at INDRA Re-source, with no additional deep-dismantling steps.

38 In 2023, average hourly labour costs in the whole economy were estimated to be €31.8 in the EU and €35.6 in the euro area. However, this average masks sizable differences between EU Member States (Bulgaria:€9.3, Romania:€11.0, Portugal €17.09, Luxembourg: €53.9, Denmark: €48), Eurostat, Hourly Labor Costs, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Hourly_labour_costs

39 "Net income" refers to the sale of spare parts and recycled materials according to ADEME and Re-source's average repartition compared to the dismantling time at Re-source. It excludes all site-specific costs that cannot be generalized, such as additional costs associated with packaging, on-site transport, storage or the additional administrative work involved in creating new material flows.

Significant steel scrap quality improvement

Shredding and post-shredding technologies

Shredders come in various designs, with varying impurity removal capacities. However, most shredders function according to a common operational principle, which is illustrated in the following model (**Figure 14**).

The shredder receives scrap metal from various sources (notably from ELVs). It reduces the size of the scrap and extracts certain materials and pollutants (metallic, ferrous and non-ferrous fractions, steriles, etc.) using magnets, eddy currents and manual sorting. These practices can largely vary, depending on the shredder. The extracted materials are then sold to specific valorization routes, while the steel scrap is sold to steelmakers as E40 scrap for re-use in steel production. Depending on the scrap quality, the produced steel and the type of furnace (BF, EAF,...) the E40 quantity used will vary.

To differentiate the impact of deep-dismantling on the steel quality from the impact of post-shredding, it is important to use a classic shredder with average post-shredding capacities.

Derichebourg's shredder (Athis-Mons, France) has a shredding capacity of 100 T/hour, removing 15-20% of impurities and thus allows a differentiated, representative analysis of the deep-dismantling.

The deeply dismantled ELV hulks are picked up by a grapple and deposited in the shredder, which crushes them in pieces smaller than 30 cm. The shredded parts then pass through various cleaning and depollution systems using magnets and eddy currents. At the end of the process, remaining copper parts (as well as other remaining impurities) are being separated manually on conveyors by two operators.

Table 1. Difference of the net income, baseline vs deep-dismantling process at Re-source

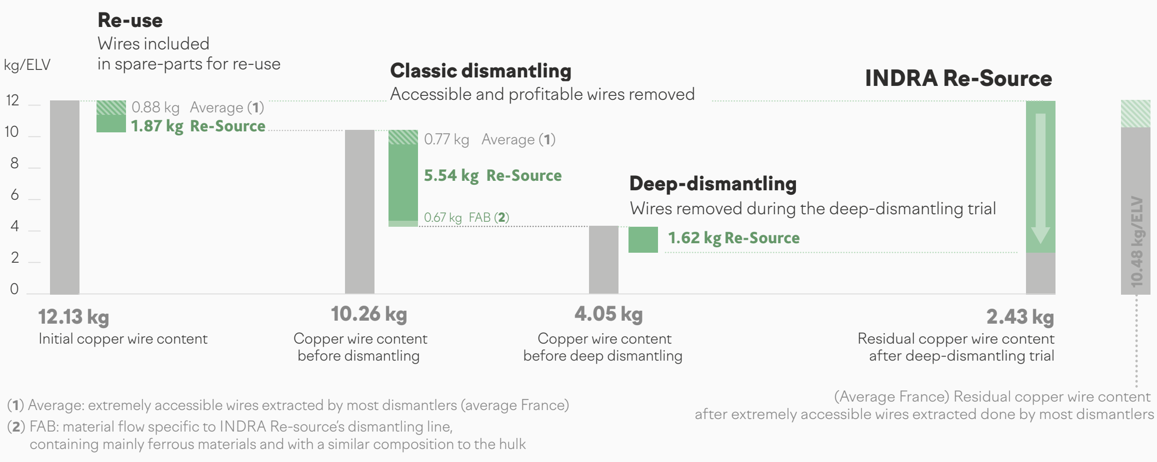
	Sale of material	Work time	Work time	Labor cost	Net income
Re-source classic dismantling	211.37 €	2.25	2H15	74.25 €	137.12 €
Re-source Deep-dismantling	214.88 €	2.37	2H22	78.10 €	136.78 €

Table 2. March 2024 prices

ELV average weight (kg)	1175
Cost of work (€/h) *	33
Hulk (€/T)	100.00 €
Copper wires (€/T)	2 500.00 €

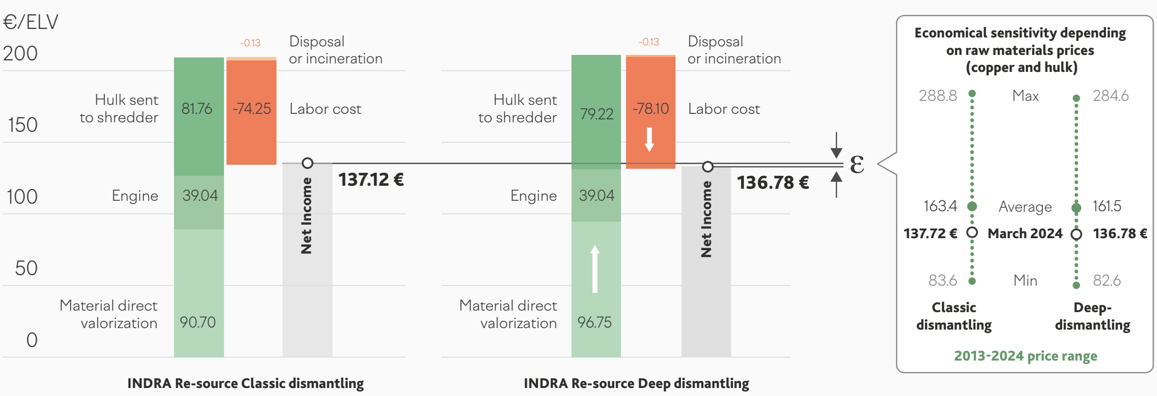
* According to INSEE (the National Institute of Statistics and Economic Studies of France), the gross annual wage of a low-skilled worker is 30300 €, working on average 1611h annually. The average share of social contributions and other charges for the employer is 43.7%. The total hourly cost for the employer (including charges) is thus of 8.81€×1.437≈27.06€/h. We chose to take a broader estimate of 33€/h.

FIGURE 12. Comparing the removal of copper wires in various processes for an average ELV of the trial



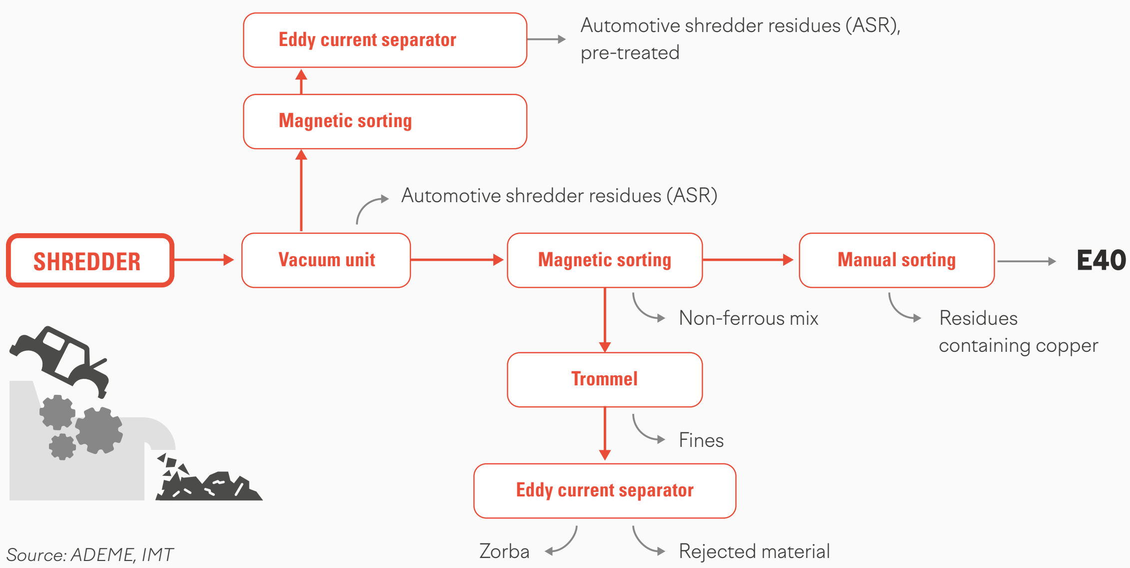
Source: INDRA. IMT.

FIGURE 13. Comparing material sales and labour costs of an average profitable dismantling process and a deep-dismantling process at INDRA Re-source



Source: INDRA, IMT.

FIGURE 14. Typical shredding and post-shredding process and material flows



Source: ADEME, IMT

For the matter of the trial, the deep-dismantled hulks were stored separately, and the shredder was cleaned before the beginning of the trial. During the trial, exclusively deeply dismantled hulks were shredded. The cleaned scrap (E40+) was stored separately before being sent to the steelmaker.

While the focus of the deep-dismantling process was set on the removal of copper wires, the shredding stage was meant to reach the required scrap size and to remove remaining impurities, mainly small copper motors, coils, electronic boards as well as remaining visible and catchable copper wires. These parts are separated manually by operators on the E40 exit belt following PST operation.

Usually, Derichebourg's shredder removes between 0.15% and 0.20% materials containing copper (% of the total mass of hulk entering the shredder). Due to the removal of additional copper wires at the dismantling stage, during the trial, the shredder only recovered 0.1% of copper containing material.

The final E40 produced during the trial represented 45.6% of the total hulk mass (80 T of E40 were removed out of the 175 T of hulk entering the shredder). Samples of the E40 exiting the shredder have been analyzed by the independent laboratory IRT M2P as well as by ArcelorMittal (on a large scale trial as well as at their R&D laboratory). **All three analyses confirm that the deep-dismantling of ELV residual wires had a significant impact on the E40 quality exiting the shredder. The produced steel scrap was of very good quality, with a high iron content and a very low copper content. Indeed, less than 0.1% of residual Cu (0.09%) were found in the E40, whereas conventional scrap contains around 0.4% residual copper. These results are encouraging since they seem to meet the steel mill inlet standards for the production of high end automotive flat steel standards, which requires an average residual copper content of less than 0.15%[40].** An important challenge that needs to be kept in mind is the management of quality control issues to enter the high-quality steel production and the necessity to keep the variation of copper content low enough. Indeed, current E40 has a large spread of quality which is hardly manageable by the steelmaking process for the production of high-quality steel.

The copper content could even be reduced to less than 0.05% if all the fragments with visible copper were removed. Screening of the material shows that the copper content decreases even more if the fragments finer than 20mm (representing 2.7% of the global scap mass) were removed. Additionally, it has been noted that a removal of steel fragments coarser than 20mm and non-made of sheets (17.6% of global scrap mass) would lead to a theoretical copper content of only 0.038%.

Those results provide some post-shredding treatment ideas to continue improving scrap quality at shredding and post shredding stages. IMT will further explore the shredding and post-shredding route in the continuation of the Car-to-car program in 2025.

40 These numbers might vary depending on the steel grade, however it provides a representative estimate of the conditions required for the automotive flat steel production.

RECOMMENDATIONS

Creating a high-quality steel scrap standard for a positive economic incentive on the ELV value chain

At present, every actor of the end-of-life ecosystem makes profit through the resale of some specific recovered parts and materials of vehicles.

Improved wire and small electric engine removal would allow a better recovery of copper for reuse as secondary raw material, this metal remaining an absolute critical material for the transition.

However, the value created through increased copper valorization is not significant enough to motivate all dismantlers to maximize copper recovery to the level achieved during this trial. On the other hand, shredders may lose a part of their revenue if the mass of copper extracted in the post-shredding process decreases. **The economical motivation of both players to proceed to increased copper extraction and sorting lies therefore in the extra value of the E40 produced due to its low copper content**.

The quality improvement, leading to a higher E40 scrap value, could be a game changer for the incorporation of this high-quality scrap into the automotive steel industry. In order to provide a predictable and commercial value to the improved E40 scrap produced, we recommend defining a new E40+ standard, which added value could be distributed all along the value chain (in the price of the copper decontaminated hulk and in the purchase price of E40+ by steelmakers). We believe that a new quality standard, differentiating E40+ from average E40, is the most effective way to negotiate a balanced added value distribution through commercial or contractual negotiations.

We thus recommend the creation of an E40+ steel scrap commercial standard (and subsequently a "hulk+" standard), which would guarantee a reduced level of copper contamination (<0.15% of residual copper).

Deep-dismantling would be one possible option to achieve the targeted result (as demonstrated in this trial). **Advanced post-shredding could be another way to improve steel scrap quality that needs to be investigated.** We plan on exploring in 2025 the technical potential of the shredding/post-shredding route to achieve the same unique quality standard.

The two approaches have the potential to complement each other, despite regional variations in relevance across the EU, given the diverse circumstances and wide range of practices among Member States. In certain countries, the dismantling network may be sufficiently developed and mature to require only minor incremental process adjustments to meet the necessary standards. Conversely, in other Member States, shredders' performances and their level of PST development might already be adequate, offering greater reliability in terms of quality control and consistency to achieve the standard requirements.

When evaluating the two options, it is crucial to consider the logistical aspects as well. If advanced PST solutions are centralized and necessitate extensive hulk transportation, the resulting economic impact and environmental footprint might warrant the implementation of a hybrid approach. This balanced solution could potentially mitigate the drawbacks associated with long-distance transportation while capitalizing on the benefits of both dismantling networks and advanced PST facilities.

In any case, the new proposed standard will spark commercial negotiations between the industrial players of the end-of-life and steel sector, influence strategic orientations of the ELV value chain actors and ultimately motivate investments.

Recommendations on the ELV Regulation

Incentivizing copper removal of ELVs in the EU regulatory framework

The market levers and tools considered here above (new E40+ standard) could also be complemented by a regulatory framework to initiate and incentivize new practices and new business opportunities. Efficient and tailored regulatory incentives and/or obligations are to be considered.

In fact, the current ELV Directive already imposes the removal of copper from ELVs at the dismantling stage, leaving open the possibility to remove it at the post-shredding stage, however without specifying any minimum copper removal rate.

Standardized and detailed recommendations regarding copper wire removal at the dismantling stage do not seem feasible nor desirable given the wide diversity of practices and vehicle models. We would therefore recommend setting objective-based regulatory quality targets for the cumulated dismantling and shredding operations rather than mandatory removal steps or mandatory specific parts removal at dismantling stage only.

We suggest that **the new European ELV regulatory framework incorporates a requirement for achieving a specific wire mass or copper mass extraction ratio**, similar to the current minimum recycling ratio obligations of 85% included in the ELV Directive and applying to the total mass of the vehicle. However, this provision should not dictate whether the extraction is to be performed exclusively by dismantlers or shredders. It should remain flexible, allowing for a combined approach of wire removal.

Indeed, all necessary reporting elements are already in place to fulfill the current directive requirements that could be focusing on copper wire recovery. Additionally, such a new copper-based obligation would bind the relationship between shredders and dismantlers since the targets will need to be reached through a combination of both extraction rates.

(Alternatively, Annexe VII of the ELV Regulation could contain an obligation to dismantle wires before shredding. However, since its implementation might potentially collide with a wide diversity of practices within the EU, control capacities would be limited.)

We suggest implementing this target no earlier than 2028. This timeline would provide Member States with **sufficient time to establish the necessary specific reporting and control procedures to meet this new requirement. These procedures could include audits, mass reporting and performance tests for shredders**, similar to those currently in place for the already existing 85% recycling target contained in the ELV Directive.

The design of these reporting and regulatory control mechanisms should serve a dual objective. Firstly, they should ensure compliance with regulatory requirements. Secondly, they should also address market needs by supporting the development of a new E40+ standard, providing steelmakers with evidence in terms of scrap quality. Such an approach would simultaneously satisfy regulatory obligations and industry requirements.

Mandatory recycled content for the production of automotive steel

In order to create an efficient demand shock, the proposal of the ELV Regulation drafted by the European Commission includes a provision offering the possibility of implementing a minimum recycled steel content. The provision requires the Commission to evaluate the possibility for new cars entering the EU market after 2030 to contain a minimum amount of recycled steel. This provision aims at providing a substantial market visibility for recycled steel demand increase, securing potential investment in the DRI-EAF route, given that it is technically possible to substantially increase the recycled content via this production route. **Indeed, there is a consensus in the EU to consider that the automotive industry should be the lead market for green steel production development in the EU. Incentivizing or mandating closed-loop recycling from ELV-derived materials to new vehicle production through a partial ELV-origin requirement for recycled steel content would primarily benefit copper recovery from ELVs, which remains a key challenge.** With regard to a mandatory recycled content target, a progressive approach is recommended including increasing recycled content ratio. **Ideally, the creation of two different targets, one applicable to flat steel and another one applicable to long steel, would be more beneficial to create an efficient and clear technical demand visibility**.

Other options could lead to similar results but need to be considered within **a multi-material approach**. A potential approach could involve developing a methodology to calculate the **carbon footprint of steel products** or **establish green steel ratios**, provided a consensual definition of green steel has been determined. **This methodology could be part of a broader framework, similar to the "eco-score"** used in France to incentivize the purchase of electric vehicles. Nevertheless, to avoid underestimating the production emissions, this eco-score should evolve over time to take into account average country-specific industry emission intensities for automotive steel.[41] It is likely that a European version of this eco-score will emerge, as evoked in the Clean Industrial Deal and the Action Plan of the European Commission for the automotive sector.[42]

We hence support any policy tools that would boost demand for recycled steel as well as facilitate and secure the development of EAF industrial capacities for flat steel production.

Additionally, we strongly advise that the ELV regulation, when introducing minimum recycled content requirements for steel or other materials, should **specify that a substantial portion of recycled material must be sourced from EU-based ELV recycling industries**. This recommendation aligns with the increasing consensus that any environmental or strategic obligations established in EU regulatory frameworks should primarily benefit EU industries, particularly the European based automotive sector. **The introduction of local content requirements (LCR) or local content scoring is a concept that is gaining traction to protect the competitiveness and resilience of the European automotive supply chain and particularly production sites based in the EU**. In that sense, the Clean Industrial Deal mentions a "minimum EU content requirement" to boost clean supply and demand to ensure lead markets for low-carbon products. This tool is relevant and should therefore be applied to recycled materials, including steel to support its decarbonisation.

Such mandatory recycled content should also be consistent with OEM's corporate CSR strategies: BMW, Renault, Volvo have already committed to increase their recycled content, steel being a potential component to contribute to this objective. The development of best practices and necessary investments needs pioneer OEM players to pull the demand.

The regulatory framework should be structured with a **progressive approach** to (1) incentivize and reward OEM's initiatives by offering a competitive advantage to leading industrial players, while (2) ensuring a level playing field by setting a deadline by which all OEMs selling cars in Europe will eventually meet the same standards at some point of time, compelling those lagging behind to catch up. This balanced approach aims to foster innovation while maintaining fair competition across the automotive industry.

Increasing the sharing of data between OEMs and ATFs for better end-of-life management

Information regarding the location of wiring in the car and conditions for access and extraction of the wiring are two enablers that need to be considered to facilitate steel scrap quality improvement and value creation at the dismantling stage.

Our study enables us to pinpoint the general distribution of these wirings in the passenger compartment, particularly at dashboard level and along the length of the vehicle's interior cabin.

Despite efforts of some actors, the upstream and downstream industry of vehicles do not exchange valuable information on challenges and difficulties they are facing, while some valuable data such as the location of copper wires are not systematically shared by OEMs or can only be accessed through the purchase of databases. This lack of information as well as the lack of a common industrial language is detrimental to the creation of an efficient circularity.

For this reason, **we recommend setting up a database accessible to the players of the ELV sector to gain access to relevant data such as the localization and quantity of certain materials such as the copper wires** (complementary to IDIS database which is not

41 They typically have a significantly higher emissions intensity than the average steel industry emission intensity, ICCT (2024) Which automakers are shifting to green steel? An analysis of steel supply chains and future commitments to fossil-free steel, https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf;

42 European Commission (2025), Action Plan to drive innovation, sustainability, and competitiveness in the automotive sector, https://ec.europa.eu/commission/presscorner/detail/en/qanda_25_636

appropriate for the targeted purpose of material value identification and extraction facilitation). The Circularity Vehicle Passport mentioned in Article 13 of the ELV Regulation could for example be a way to share the necessary data.

Improved eco-design practices

Beyond improving information exchange between stakeholders, it is also essential to **anticipate the end-of-life of future vehicles and therefore reflect today on the best way to facilitate the management of their end-of-life**. From the initial design and engineering phases of a new car model's development, it is crucial to incorporate key best practices and guidelines. These should be aimed at facilitating end-of-life treatment processes and enhancing the recovery of quality materials and value of the vehicles.

The **removal of copper wires would be greatly facilitated by an adapted wiring architecture** that enables the removal of major cables through pulling, without disassembling parts such as the dashboard or doors. Another option to **facilitate repair and replacement as well as re-use of some parts** would be the introduction of a plug-and-play solution, for example to connect a vehicle's door.

A more global principle of automotive eco-design best practices would be the **durability of the use of a material or practice to facilitate the long-term management of end-of-life vehicles**. Indeed, regular changes in configuration and materials require constant adaptation of dismantling practices, as well as increasingly varying vehicle models complicate the task for dismantlers, notably for small structures without dedicated engineering capacities.

Hence, a certain degree of uniformity in design within a brand (or even more globally), could help standardize the dismantler's processes and facilitate the removal of wires. Some manufacturers already design their vehicles fairly uniform and place the wires systematically at the same locations, which facilitates their extraction, provided the wiring is easily accessible.

Next steps: quality control and improved post-shredding methods

In this study, we focused on the removal of copper-containing wires at the dismantling stage. However, other components containing copper, such as small motors and coils, were also present in significant quantities during our trial at the shredding stage. These parts are hardly accessible during the dismantling stage.

As the presence of these components in vehicles increases, it is also important to focus on their removal, which will almost certainly have to take place at the shredding and post-shredding stages, since these components cannot be extracted manually - unless the vehicle is fully disassembled.

Shredding and post-shredding methods allow *in fine* potentially the best quality control of the steel scrap, which is a crucial issue for steelmakers for it to be incorporated in the production of high-quality flat steel. This highlights the need to focus on post-shredding capabilities and the impact of additional manual sorting on the shredding line. The goal is to identify the optimal combination of dismantling and shredding to maximize technical-economic performance and circularity.

During this first trial, we noticed the positive potential of increased manual or automated sorting on the shredding line for the removal of copper components. We wish to pursue our research with a second project, focused this time on the improvement of steel scrap quality through the strengthening of copper removal at the shredder. Various options will be screened including manual or automated processes, quantified in terms of cost and quality performance (including both stability and quality levels).

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ANNEXES

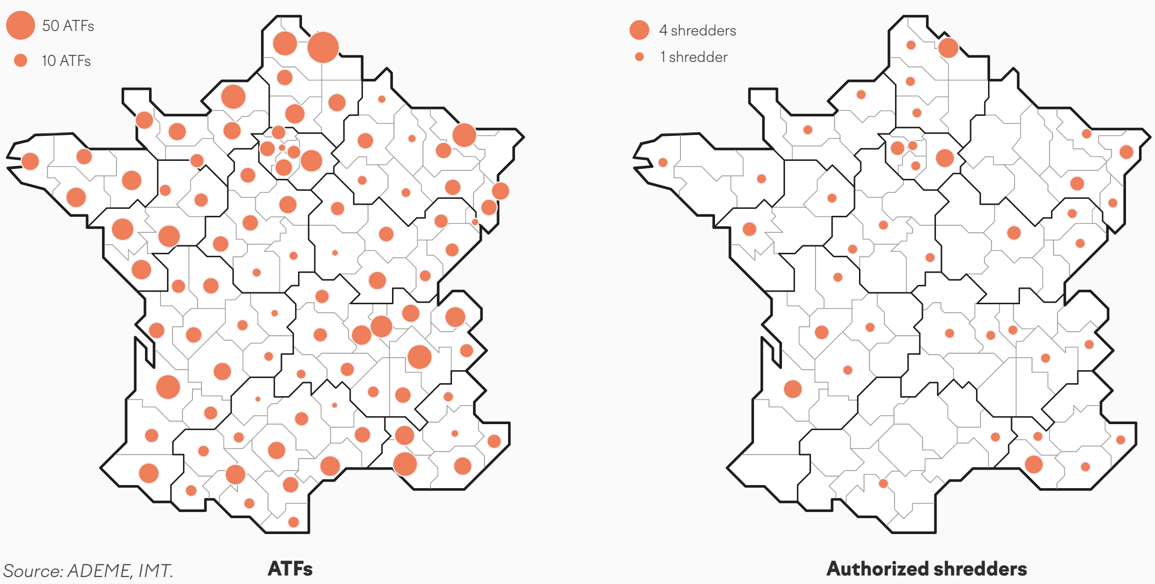
Repartition of the ELV value chain in France

France has some 1,700 CVHUs spread across the country, with very broad disparities regarding their size and practices.

As mentioned above, the ELV goes through several extraction stages to remove components and materials for reuse and recycling. The hulk and materials remaining in the vehicle when leaving the ATF are then sold to a shredder.

As a matter of comparison, only around 50 shredders are distributed throughout France, with very different shredding capacities and diverse post-shredding treatment methods (**Figure 15**).

FIGURE 15. Number of ATFs and authorized shredders per department



Source: ADEME, IMT.

Sampling methodology and analyses performed

Calculation of the rate of copper wires in the ELV

The theoretical wire content of the ELV used during the trial was based on internal data of Re-source. Indeed, Re-source used to fully dismantle certain Renault vehicles of various ages and segments to determine their exact content of copper wire.

Since vehicles of a certain segment and age usually contain the same options and equipments, these "reference vehicles" are considered as being representative to their equivalent of another brand regarding their wire content. To determine the theoretical average copper content of the trial ELVs, we hence classified the vehicles of our trial by segment and age and deduced the quantity of wires contained based on our "reference vehicles".

Residual copper content calculation

The analysis of our E40+ sample requires in a first step to determine the composition of the scrap sample to better understand which parts of the ELVs make up the E40 and where the various pollution sources originate from.

The characterization of the E40+ sample was provided by the independent laboratory IRT M2P and composed of three main steps.

A similar characterization was performed by the R&D laboratory Maizières of ArcelorMittal. Additionally, large-scale trials were performed at the steel mill in Ghent (ArcelorMittal) and will be detailed in the next section.

Firstly, the scrap samples were recovered at the shredder. Two scrap samples of 150 to 200 kg, representative of the produced E40+ scrap, were collected, weighted and sent to the characterization site of IRT M2P (Uckange, France).

In a second step, the samples were again weighted and manually sorted (manual characterization). Each sample was separated into 4 fractions: mechanical steel, steel sheets, elements containing visible copper and elements containing visible sterile. Each of these fractions was weighed and melted (melting test) to be metallurgically characterized (VIM melting of each sample separately in air, metal sampling during melting, characterization of elements: Fe, Cu, Cr, Ni, P, S, Mn, Mo, Al, Si, Mg, Ti, C), weighing of the metal obtained to assess iron content). Each of these 3 tasks will be detailed and the main results obtained will be presented in the following paragraphs.

This second step of the trial allows, through melting, to characterize the exact chemical composition of the steel scrap and determine its precise quantity of pollutants as well as its potential suitability for reintroduction in the production of steel.

For comprehension purposes, it is important to differentiate parts remaining in the scrap and being composed of more or less copper, visible to the naked eye (called for terminology purposes "fragments containing visual copper"[43]), from copper as a chemical element and present as a final residual pollution source in the steel.

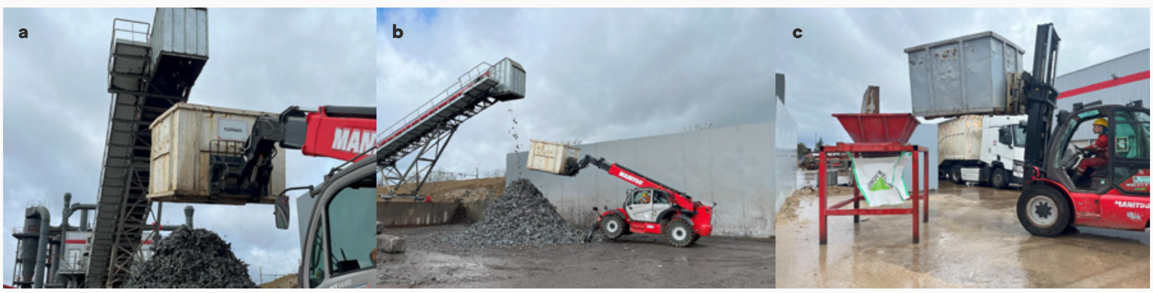
Sample collection

The samples were taken during the shredding process on April 4th, 2024, at Derichebourg's shredder in Athis-Mons, over half a day.

The sampling protocol was defined according to waste sampling standards, to collect a minimum of 650 kg (representative of the steel content of a shredded ELV). Sampling was carried out in three stages over the duration of the shredding process, and three samples of around 220 kg were taken. The collection took place alternately under the scrap flow, at a rate defined on the basis of the theoretical scrap flow rate (calculated from the shredding speed of ELVs). The cadence was adapted over the course of the sampling campaign to ensure the most homogeneous sampling possible, since the shredder does not always operate at a constant rate due to technical contingencies (**Figure 16**).

43 By "fragments containing visual copper" are meant parts and materials visible to the naked eye, containing a trace of copper. They can be fully composed of copper, or only be copper-coated.

FIGURE 16. Sampling
a. under the conveyor, **b.** under E40 scrap flow and **c.** sample being loaded into a big bag



Manual characterisation

The first step in the characterization process is a manual sorting of each of the three samples to identify and quantify fractions of different kinds (ferrous metals, cuprous metals, steriles and fines/dust).

This stage involves spreading each sample in its entirety and separating each residue by hand, one by one, by visual identification. In preparation for further work (smelting and metallurgical characterization), each sample was further sorted and finally broken down into the 6 fractions detailed in the table below. Examples of residues from the different categories are shown in **Figure 17**. The sheet metal and mechanical parts were also sorted by size ("large residues" (> 50 mm) and "small residues" (between 5 and 50 mm) **Table 3**).

The results of the manual characterization are presented in the table below. There are some differences in the distribution of the mass fractions of sheet metal,

FIGURE 17. Example of residues:
a. sheet metal, **b.** mechanical parts, **c.** steriles, **d.** residues containing steriles, **e.** fragments containing visual copper

Table 3. Manual characterisation

Nature	Description
Sheets	Steel sheets (thickness < 3mm)
Mechanical parts	Casting parts
	Parts containing assembly éléments (screws, nuts, rivets, etc.)
	Ball bearings
	Springs, wires, bars
	Tubes
	Screws, nuts, washers
	Magnet pieces
	Steel sheets (thickness > 3mm)
Steriles	Rubber
	Textiles
	Textiles yarns
	Foam
	Other polymers
	Wood
	Glass
	Minerals (concrete…)
Residues containing steriles	Mechanical residues/sheets containing elements of the "sterile" category*
Residues containing copper	Copper wires
	Motors/rotors/stators
	Copper-plated elements (wires, screws, bronze...)
	Connectors
Fines	Residues of less than 5 mm

* Most of these samples are solid scrap metal residues, containing a piece of rubber or textile (i.e. essentially scrap metal).

mechanical parts and steriles, which can be explained by the subjectivity of manual sorting and the distinction made between scrap fragments with and without steriles.

For each sample, the total mass share of these three fractions (sheet metal, mechanical parts and residues containing visible steriles) represents over 98.5% of the total mass (the remainder being divided between pure steriles, residues containing copper and fines).

For these last three categories of remainder, their respective mass shares vary, but keep the same orders of magnitude:

- between 0.24 % and 0.50 % pure steriles,
- between 0.19 % et 0.83 % residues containing copper
- between 0.13 % et 0.33 % fines.

The main significant difference relates to the copper fraction in sample E2, which is two to four times higher than in the other samples. As copper is one of the elements of interest in this study, a more detailed analysis was carried out, detailing the composition of this copper fraction (**Figure 18**).

This difference is mainly due to the presence of heavy elements containing predominantly steel, or whose nature, for some, is not identifiable to the naked eye, but whose orange color may suggest the presence of copper elements or coating(s). An overview of the contents of the copper fraction of each sample is shown in **Figure 19** and **Figure 20**.

There also remain small differences in the fines fraction, but these can be attributed to variations in the sampling process, notably material losses due to weather conditions.

FIGURE 18. Detail of the copper fraction (sample E1)

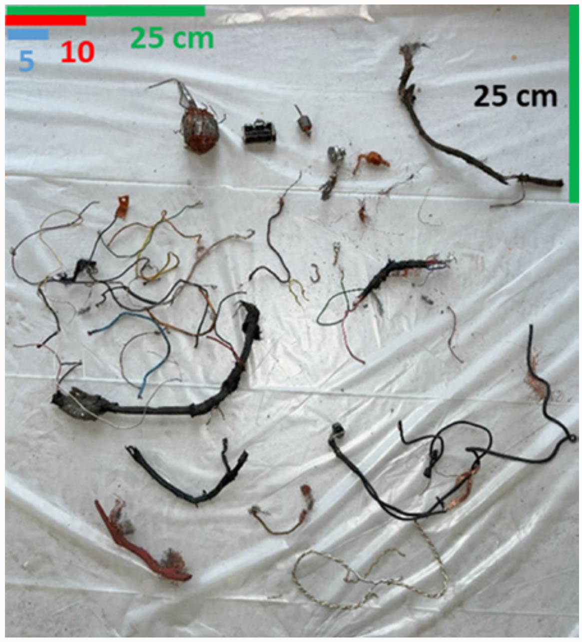


Table 4. Mass fractions obtained for the 3 different samples

	E1		E2		E3		Global	
	Mass [kg]	Share [%]	Mass [kg]	Share [%]	Mass [kg]	Share [%]	Mass [kg]	Share [%]
Sheets	122.55	59.04%	109.6	43.17%	118.7	59.34%	350.85	53.0%
Mechanical parts	78.73	37.93%	123.69	48.72%	66.4	33.19%	268.82	41.6%
Residues containing steriles	4.79	2.31%	17.53	6.91%	12.9	6.45%	35.22	5.3%
Pure steriles	0.63	0.30%	0.61	0.24%	1	0.50%	2.24	0.34%
Residues containing copper	0.59	0.28%	2.11	0.83%	0.39	0.19%	3.09	0.47%
Fines	0.28	0.13%	0.32	0.13%	0.66	0.33%	1.26	0.19%
Total	207.6		253.9		200.1		661.5	

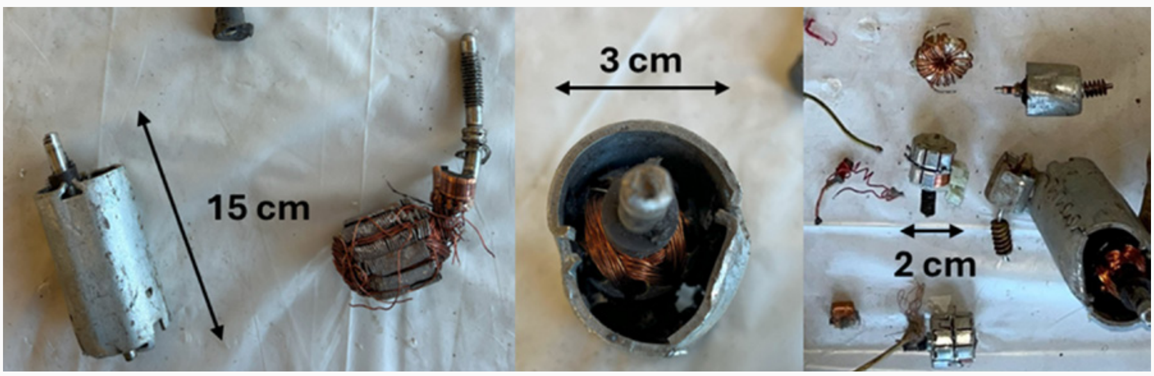
Table 5. Details of the fractions containing copper in the 3 samples

	E1		E2		E3	
	Mass [kg]	Share [%]	Mass [kg]	Share [%]	Mass [kg]	Share [%]
Wires with sheaths	0.06	10.3%	0.08	3.8%	0.065	16.3%
Bare copper (wires, connectors, etc.)	0.01	1.7%	0.01	0.5%	0.02	5.0%
Inductor	0.34	58.1%	0.8	38.3%	0.03	7.5%
Fragment containing mainly steel	0.05	8.5%	1.16	55.5%	0.235	58.8%
Fragment containing mainly polymer	0.125	21.4%	0.02	1.0%	0.045	11.3%
Other	0	0.0%	0.02	1.0%	0.005	1.3%
Total	0.585		2.09		0.4	

FIGURE 19. Detail of the cuprous fraction of sample E2 (left) and close-up of undetermined fractions considered to be "cuprous" (right)

FIGURE 20. Detail of the copper fraction of sample E3 (left), close-ups of the largest cables, connector elements and small inductors (right).

FIGURE 21. Close-up of inductors in sample E2



Most of the elements found in the cuprous fragments are wires and inductors (70% for E1, 43% for E2 and 29% for E3). Large wires (for example, the one shown in **Figure 20** at the top right) and inductors (for example, **Figure 21**) are theoretically easily identifiable and could be removed manually by operators on the shredding belt. We noticed that during the last period of sampling, the addition of an operator on the shredding belt led to less residual copper wires and inductors in the sample E2. Similarly, following a process phase of the shredder with a higher scrap flow (and most certainly a reduced crushing intensity), the proportion of fragments containing copper is higher than at the beginning (E1) and end (E3) of the process.

It should also be noted that the inductors are of different sizes (on the right in the image below) and that small inductors are more complicated to identify and extract manually from a belt and can be hidden in some casing (central image below). Improved eco-design as well as additional training of the operators to recognize some specific vehicle parts could reduce the risk of residual copper in the E40. (**Figure 21**).

The smallest cables and wires were generally found hanging on sterile fractions (foams and textiles in particular). Increased manual sorting or a longer shredding process could potentially reduce the proportion of these polluting materials, and thus the proportion of small copper wires clinging on them.

Melting and chemical analysis

In a second stage, the scrap is melted to steel in an oven, and the steel is analyzed chemically to determine its exact composition and metallic performance.

The following melting process was adopted to melt the sample and carry out the characterization:

- Cold charging of the Vacuum Induction Melting (VIM) furnace, firstly with the “fine” and “sterile” fractions, then the compacted scrap cylinders were placed on top,
- Closing of the furnace enclosure,
- Slow temperature rise to allow combustion of the “sterile” elements, and evacuation of the fumes produced,
- Melting of the charge,
- Two samples are taken from the liquid bath, weighed and analyzed,
- Addition of copper fraction,
- New samples taken, weighed and analyzed,
- Liquid metal poured into ingot mold,
- Weighing of the metal produced after cooling.

The “fragments containing visual copper” are only added in a second melting phase to the scrap in order to differentiate the residual copper contained in the residues from the copper contained in the alloys that make up the scrap, to eventually determine the best theoretically possible scrap quality.

The analysis was carried out using the ARL iSpark 8880 spectrometer, which analyzed the following elements: Fe, C, Cu, Cr, Ni, P, S, Mn, Mo, Si, Mg, Ti. (**Table 6**).

These results show that a small amount of copper (< 0.05%) is present in scrap metal, excluding elements identified as “cuprous” and could theoretically be removed if identified as pollutants during the process. This copper can come from several sources:

- Copper contained in certain parts (polluting alloying element),
- Copper elements “trapped” in residues, and therefore invisible,
- Presence of copper in the “fines” fraction
- Coated mechanical elements or parts that would have passed as scrap during manual sorting

The second analysis, carried out on the metal after addition of the copper fraction, is detailed below and shows a residual copper content of less than 0.1% re-

Table 6. Analyses carried out on the metal obtained after scrap melting without the addition of the “fragments containing visual coppers”

%	Fe	Cu	Cr	Ni	P	S	Mn	Mo	Al	Si	Mg	Ti	Others [1]
Without visual Cu residues	95.396	0.0478	0.0948	0.039	0.0221	0.02	0.0371	0.0149	0.0049	0.0353	0.0002	0.0006	0.053

1 This category includes elements such as carbon and oxygen, but also elements lost in the fumes (fire losses), notably waste rock, which is not found in the metal fraction after smelting.

sidual copper contamination of E40 (vs. current copper pollution of E40 around 0.25- 0.4% today). This E40+ could thus be suitable in increased quantities for the production of high quality flat steel (**Table 7**).
These positive quality results were confirmed by a laboratory analysis provided by the R&D laboratory Maizières of ArcelorMittal.
Additional sorting by the steelmaker in laboratory conditions also showed that if a technical solution to automatically remove the steel fragments non-made of sheets in the fraction coarser than 20 mm, the remaining 82.4% of the initial E40 scrap would have a copper content of only 0.038%. These results need to be confirmed large scale and in industrial conditions, but already represent an interesting way for further research

Large-scale analysis ArcelorMittal
In collaboration with ArcelorMittal, 45 tons of the produced E40+ were used in a BF-BOF in summer 2024, using production conditions identical to the EAF route, to produce a high quality flat steel coil, to determine whether it met the quality requirements for high-quality automotive flat steel and could be used in large quantities in an EAF (with several EAFs in operation around the world, the steelmaker can use its internal knowledge and experience on EAFs to recreate similar conditions of an EAF in a BF-BOF). The E40+ was used in two heats, with a E40+ input of 6% and 5% and provided similar positive results than the laboratory, being thus suitable for a use in higher proportions for the production of high-quality flat steel, given its quality remains stable and predictable. The further trial of IMT in 2025 will focus on this aspect of quality control, notably using shredding and post-shredding techniques.

Table 7. E40 scrap analysis results

%	Fe	Cu	Cr	Ni	P	S	Mn	Mo	Al	Si	Mg	Ti	Others
E40	96.68	0.09	0.04	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	3.065

The Institute for Mobility in Transition (IMT) is a spinoff of IDDRI (Institute for sustainable development and international relations) initiated in 2021. The organisation is a French independent think tank dedicated to the transition of the transport sector in France and Europe.
The aim is to objectify the environmental, social, industrial, and political issues at stake to facilitate the operational implementation of this transition. IMT produces analyses and recommendations to help French and European public decision-makers understand the issues, and to facilitate dialogue between stakeholders. The work is based on (1) multi-stakeholder consultation, within a platform that brings together players from diverse backgrounds to exchange ideas in a framework protected by the Chatham House Rule, (2) on a modeling tool comprising various databases, and (3) collaborations with European & international organisations on specific topics. The scope of scrutinised subjects includes amongst others: the decarbonisation of road transport, access to clean transportation, critical raw material supply and recycling, etc.