POLICY BRIEF

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Closing the loop: Improving automotive steel recycling for a circular economy

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INTRODUCTION

A more circular economy, based on the reuse and recycling of products and materials, can reduce the European Union (EU)'s dependency on raw material imports, lower greenhouse gas (GHG) emissions, and mitigate the environmental and social impacts of mining. In February 2025, the European Commission published the Clean Industrial Deal, a flagship strategic action plan to boost the European Union's decarbonization, competitiveness, and resilience.[1] One of its main objectives is to improve the circularity, reduce waste and promote recycling, reuse and sustainable production.

The automotive industry is one of the European Union's most resource-intensive sectors. In 2023, the Commission stated that it was responsible for over 7 million tonnes (Mt) of steel demand per year, 19% of the EU total.[2] As the average mass of new passenger cars grew by 21% from 2001 to 2023, material demand also increased.[3] Typical passenger cars in the European Union are estimated to contain about 800 kg of steel.[4] As we evaluated in a recent report, the steel used in vehicle production in

1 European Commission, *The Clean Industrial Deal: A Joint Roadmap for Competitiveness and Decarbonization* (February 26, 2025), https://commission.europa.eu/document/download/9db1c5c8-9e82-467b-ab6a-905feeb4b6b0_en?filename=Communication%20-%20Clean%20Industrial%20Deal_en.pdf.

2 European Commission, 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, COM/2023/451 final (July 13, 2023), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52023PC0451.

3 Michelle Monteforte, Peter Mock, and Uwe Tietge, *European Vehicle Market Statistics 2024/25* (International Council on Clean Transportation, 2024), https://theicct.org/publication/european-vehicle-market-statistics-2024-25/.

4 Anh Bui et al., *Technologies to Reduce Greenhouse Gas Emissions from Automotive Steel in the United States and the European Union* (International Council on Clean Transportation, 2024), https://theicct.org/publication/technologies-to-reduce-ghg-emissions-automotive-steel-us-eu-jul24/.

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Europe has a high GHG emissions intensity.[5] In addition, the impact of primary steel production extends beyond the emissions of steel production itself to include the environmental and social implications of iron ore and coal mining and refining.

A more circular use of steel can mitigate these impacts, but only if increasing the use of recycled steel in vehicle production in Europe does not divert the use of recycled steel from other sectors or regions. Therefore, increasing the use of recycled steel in vehicle production needs to be complemented by efforts to enhance its overall availability and quality.

As more products containing steel are reaching the end of their useful lives globally, steel scrap availability is expected to increase by more than 50%, from about 850 Mt per year in 2023 to 1,300 Mt per year in 2050.[6] Even in a mature market like the European Union, the total scrap available is estimated to increase, from about 120 Mt per year in 2020 to about 130 Mt per year in 2050.[7] With an efficient recycling process, recycled steel could meet up to half of global steel demand in 2050, up from 35% today.[8] This could absorb all growth in global steel demand and thereby avoid the expansion of primary steel production.

During the steel recycling process today, the high-quality steel present in cars ends up mixed with several polluting elements and materials, which makes the resulting recycled steel only usable in lower-grade applications, a phenomenon referred to as downcycling.[9] Further, the quality of recycled steel is continuously downgraded upon repeated recycling. While diluting contaminated steel scrap with high-quality primary steel may offer a short-term fix to steel scrap quality deterioration, in the longer term this could render steel scrap unsuitable even for high-tolerance applications, eventually resulting in the disposal of steel scrap.[10] For a more circular use of steel, avoiding downcycling and maintaining a high quality of steel recycled from vehicles—especially by controlling for copper contamination—are fundamental.

In 2023, the European Commission proposed a regulation on circularity requirements for vehicle design and management of end-of-life vehicles, which would replace and combine prior directives on end-of-life vehicles and on type-approval of motor vehicles with regard to their reusability, recyclability, and recoverability.[11] The proposal does not set a target for recycled steel in newly type-approved vehicles in the European Union, but it enables the Commission to do so through a following delegated act, after a feasibility study. In December 2024, Member States discussed the possibility of

5 Marta Negri et al., *Which Automakers Are Shifting to Green Steel? An Analysis of Steel Supply Chains and Future Commitments to Fossil-Free Steel* (International Council on Clean Transportation, 2024), https://theicct.org/publication/green-steel-automakers-us-europe-sep-24/.

6 Baris Bekir Çiftçi, "The Future of Global Scrap Availability," *Worldsteel.Org* (blog), May 2, 2018, https://worldsteel.org/media/blog/2018/future-of-global-scrap-availability/.

7 Sabine Dworak, Helmut Rechberger, and Johann Fellner, "How Will Tramp Elements Affect Future Steel Recycling in Europe? – A Dynamic Material Flow Model for Steel in the EU-28 for the Period 1910 to 2050," *Resources, Conservation and Recycling* 179 (April 2022): 106072, https://doi.org/10.1016/j.resconrec.2021.106072.

8 Julian M. Allwood et al., *Steel Arising: Opportunities for the UK in a Transforming Global Steel Industry* (University of Cambridge, 2019), https://libertysteelgroup.com/wp-content/uploads/2021/05/STEEL-ARISING-200319.pdf; World Steel Association, *Scrap Use in the Steel Industry* (2021), https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf.

9 Christoph Helbig et al., "A Terminology for Downcycling," *Journal of Industrial Ecology* 26, no. 4 (2022): 1164–74, https://doi.org/10.1111/jiec.13289.

10 Dworak, Rechberger, and Fellner, "Tramp Elements."

11 European Commission, Proposal for a Regulation on Circularity Requirements for Vehicle Design and on Management of End-of-Life Vehicles; "End-of-Life Vehicles,"European Commission, accessed October 7, 2024, https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en.

introducing a recycled steel quota in the proposed regulation at the time of its entry into force, as opposed to through a later delegated act.[12]

This policy brief discusses approaches to incentivizing a more circular use of automotive steel in the European Union. We explore the challenges and opportunities of increasing the quantity and quality of steel recovered from the recycling of vehicles, discussing the potential displacement effects and its technical and economic feasibility. We also explore how the current use of steel varies across vehicle models and manufacturers. The brief closes with possible policy options for incentivizing a more circular use of automotive steel, with a focus on the recycled steel quotas currently being debated by the European Commission.

BENEFITS AND LIMITATIONS OF RECYCLED STEEL IN VEHICLE PRODUCTION

CLIMATE AND ENVIRONMENTAL BENEFITS

The steel used by major automakers in Europe is estimated to have an emissions intensity above the regional steel industry average.[13] This is because the steel producers supplying these major automakers have a disproportionally high share of coal-based blast furnace-basic oxygen furnace (BF-BOF) technology installed compared with the regional average.

The emissions intensity of recycled steel in the European Union is estimated to be 0.7 tonnes of CO_2 equivalent (CO_2e) per tonne of steel, compared with an emissions intensity of 2.1 tonnes of CO_2e for primary steel produced through the BF-BOF steelmaking pathway.[14] A 30% share of recycled steel thus corresponds to 20% lower emissions than using solely primary steel, or a reduction of 0.4 tonnes of CO_2e per tonne of steel. For the 12.5 million passenger vehicles and light commercial vehicles produced in the European Union in 2022, a recycled content of 30% compared with using solely primary BF-BOF steel would correspond to 3.7 Mt lower CO_2e emissions. This is based on an estimated average production-weighted steel content of 434 kg for the body-in-white, derived from our analysis of S&P Global Mobility data, and considers that the body typically contains 60% of the steel in vehicles, as estimated by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model.[15] Overall, this results in an average of 722 kg of steel per vehicle.

As producing steel via the BF-BOF pathway requires coal (in the form of coke) and iron ore as inputs, the environmental and social implications of raw material mining also need to be considered. Recycled steel produced in EAFs only requires about 5–12 kg of coal for each tonne of steel, compared with the 770 kg needed in the BF-BOF pathway.[16] The GHG impacts of coking coal mining, especially methane emissions, are significant and often unaccounted for.[17] The BF-BOF pathway also requires about

12 General Secretariat of the Council, "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 – Policy Debate" (Interinstitutional File 2023/0284, December 2, 2024), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_16276_2024_INIT.

13 Negri et al., *Which Automakers Are Shifting to Green Steel?*

14 Bui et al., *Technologies*.

15 S&P Global Mobility, *AutoTechInsight; BiW Forecast April 2024: Light Vehicle Production Forecasts*, 2024, https://www.spglobal.com/mobility/en/products/automotive-light-vehicle-production-forecasts.html; Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)*, October 2022, https://www.osti.gov/doecode/biblio/81029.

16 Lina Kieush et al., "Utilization of Renewable Carbon in Electric Arc Furnace-Based Steel Production: Comparative Evaluation of Properties of Conventional and Non-Conventional Carbon-Bearing Sources," *Metals* 13, no. 4 (April 2023): 722, https://doi.org/10.3390/met13040722.

17 Sabina Assan, "The EU's steel industry and its methane problem," *Ember*, March 4, 2025, https://ember-energy.org/latest-insights/the-eus-steel-industry-and-its-methane-problem/.

1.6 tonnes of iron ore per tonne of steel.[18] Mining iron ore is connected to various environmental impacts, including land and habitat destruction, water stress, and long-term pollution of soil and water.[19] The recovery and use of recycled steel could reduce the need for mined materials, thus easing the impact on the environment.

IMPORT DEPENDENCY FOR COAL AND IRON ORE

The European Union is a net importer of key production inputs for steel. In 2022, 40 Mt of coking coal, primarily from Brazil, Canada, South Africa, and Ukraine, were used in EU steel plants to produce coke.[20] In the European Union, only Poland and Czechia produce coking coal domestically; collectively, however, this production only makes up 1.4% of global supply.[21] The European Commission has considered coking coal a critical raw material since 2014.[22]

The European Commission reports an import dependency of 77% for iron ore (which is not listed as a critical raw material).[23] The European Union imports iron ore mostly from Brazil, Canada, Ukraine, South Africa, and Russia.[24] Increasing the share of recycled steel used in the automotive sector could ease dependencies on foreign suppliers for strategic and critical raw materials.

INVESTMENT SECURITY IN GREEN STEEL PLANTS

There are two main pathways for the production of low- or near zero-emission steel. One (the DRI-EAF pathway) combines DRI using hydrogen produced with renewable electricity with EAFs powered by renewable electricity. The other (the scrap-based pathway) uses EAFs to process recycled steel.[25] The two pathways can be used in combination by increasing the share of scrap steel in the DRI-EAF pathway.

A large share (45%) of current EU steelmaking capacity consists of EAFs, while DRI capacity will require considerable investments to scale up.[26] As the DRI-EAF pathway continues to mature, increasing the use of recycled steel produced with EAFs in the scrap-based pathway would therefore allow the European Union to increase the flexibility and resilience of green steel production, reducing investment uncertainty and helping securing capital for future steel production with the green hydrogen-based DRI-EAF pathway.

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18 Eurofer, *Iron Ore and the European Steel Industry* (2013), https://www.eurofer.eu/assets/publications/archive/archive-of-older-eurofer-documents/2013-IronOreFC.pdf.

19 "Environmental Impacts of Iron Ore Mining," UK Green Building Council, accessed September 27, 2024, https://ukgbc.org/our-work/topics/embodied-ecological-impacts/iron-ore/; John Baeten, Nancy Langston, and Don Lafreniere, "A Spatial Evaluation of Historic Iron Mining Impacts on Current Impaired Waters in Lake Superior's Mesabi Range," *Ambio* 47, no. 2 (March 2018): 231–44, https://doi.org/10.1007/s13280-017-0948-0.

20 "Critical Raw Materials," European Commission, accessed September27, 2024, https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en; Eurostat, *Coal Production and Consumption Statistics*, accessed March27, 2023, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Coal_production_and_consumption_statistics; Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), *Study on the Critical Raw Materials for the EU 2023 – Final Report* (Publications Office of the European Union, 2023), https://op.europa.eu/en/publication-detail/-/publication/57318397-fdd4-11ed-a05c-01aa75ed71a1.

21 Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *Study.*

22 Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020 (Text with EEA relevance), OJ L, 2024/1252 (May 3, 2024), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401252.

23 Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *Study.*

24 TrendEconomy, *Annual International Trade Statistics by Country,* accessed November 15, 2023, https://trendeconomy.com/data/h2/EuropeanUnion/2601.

25 Bui et al., *Technologies.*

26 "European Steel in Figures 2024," Eurofer, 2024, https://www.eurofer.eu/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2024.

Additionally, although the initial investment and operational costs of DRI plants are forecast to decrease significantly in the coming years due to an expected decrease in green hydrogen production costs, current production of green steel still requires higher capital investments.[27] Recycled steel thus allows for more immediate reductions in GHG emissions at comparably low cost.

COPPER RECOVERY AS A SIDE BENEFIT

Expanding the recovery of steel from vehicles will require advancements in recycling practices, as current steel scrap management methods do not consistently produce materials of the necessary quality. Improved recycling of vehicles would reduce the pollution of recycled steel with copper and improve copper recovery.

Copper, considered a strategic raw material by the European Commission, is used in large quantities (20 Mt in 2020) for electrification across all strategic technologies.[28] With the projected expansion of the electric grid, in particular for the integration of renewable energies and increasing electricity demand from industry and households, the International Energy Agency expects demand for copper to more than double globally in 2050 compared with 2023.[29] Copper is largely mined outside of the European Union,[30] with EU production making up only 4% of global supply share.[31]

The transportation sector uses around 12% of copper globally, primarily for wiring, and a typical battery electric vehicle can contain up to 80–100 kg of copper.[32] Currently, about 1 Mt of copper scrap generated in the European Union each year is neither collected nor recycled, or is exported to be recycled somewhere else.[33] This presents a strong economic incentive to improve recycling practices.

USE OF RECYCLED STEEL IN EU CARS

This section provides insights into what types of steel are used in the automotive industry and to what extent recycled steel is currently used for vehicle production.

TYPES OF STEEL USED IN VEHICLE PRODUCTION

As noted above, passenger car and light commercial vehicle models produced in Europe in 2023 had an estimated production-weighted average of 434 kg of steel in their body-in-white, which represents roughly 60% of the steel used in the vehicle. Another 30% of the steel is used in the chassis, and the powertrain and transmission systems account for the remainder.[34] About 80% of the steel in cars consists of flat

27 Ali Hasanbeigi, Cecilia Springer, and Hannah Irish, *Green H2-DRI Steelmaking: 15 Challenges and Solutions* (Global Efficiency Intelligence, March 2024), https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/663f2cc2c440a83768c59258/1715416296800/R6+Green+DRI+Steelmaking_.pdf.

28 Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *Study*.

29 International Energy Agency, *Global Critical Minerals Outlook 2024* (2024), https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf.

30 International Energy Agency, *Global Critical Minerals Outlook 2024*.

31 Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), *Study on the Critical Raw Materials for the EU 2023 – Final Report* (Publications Office of the European Union, 2023), https://op.europa.eu/en/publication-detail/-/publication/57318397-fdd4-11ed-a05c-01aa75ed71a1.

32 International Copper Association, *Copper Recycling* (2021), https://internationalcopper.org/resource/copper-recycling/; Argonne National Laboratory, *GREET,* October 2022; International Copper Association, *The Electric Vehicle Market and Copper Demand* (2017), https://internationalcopper.org/wp-content/uploads/2017/06/2017.06-E-Mobility-Factsheet-1.pdf.

33 EU Recycling Industries' Confederation, *Metal Recycling Fact Sheet* (2020), https://circulareconomy.europa.eu/platform/sites/default/files/euric_metal_recycling_factsheet.pdf; International Copper Association, *Copper Stock & Flows, 2018* (2020), https://internationalcopper.org/wp-content/uploads/2021/08/EU28_2018-2020-08-19.png.

34 Data in this section are from S&P Global Mobility, *AutoTechInsight; BiW Forecast April 2024,* and Argonne National Laboratory, *GREET,* October 2022.

steel products, whose high ductility and surface quality requirements depend on low shares of copper contamination.[35]

Figure 1 illustrates the car body with the body-in-white components labeled, and Figure 2 presents the production-weighted average distribution of the steel used in these components. Out of the total steel used in the car body, most is used in the underbody, pillars, and doors, although there is high variability across models. These components have different performance requirements.[36] Exterior body panels like doors, hoods, and roofs usually require high stiffness and dent resistance, as well as high quality surface finishing and complex geometries. Longitudinal and lateral beam sections provide tensile, compressive, and bending stiffness or impact resistance. They usually are composed of several layers and require a variety of strength grades based on their function.

Figure 1
Body-in-white components

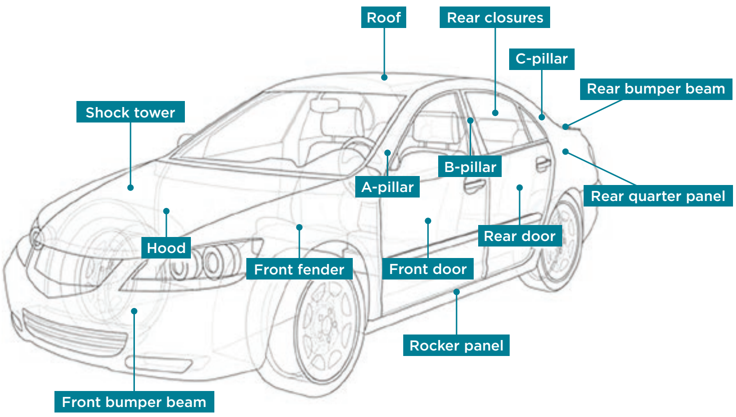
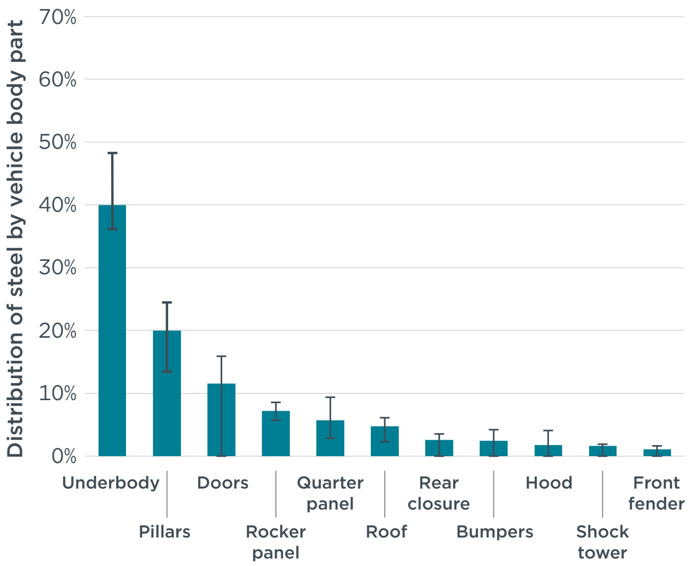


Figure 2
Production-weighted average distribution of steel over the vehicle body



Source: S&P Global Mobility, *AutoTechInsight; BiW Forecast April 2024.*

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The error bars in Figure 2 represent the range between the 10th and 90th percentiles for each component's share of the total steel in the body, highlighting considerable variability across models. For further illustration, Figure 3 displays the use of steel types and aluminum for four selected vehicle models with the highest sales in Europe in 2023.

35 "Automotive Steel Weight Analysis," Metals Consulting International, accessed September 27, 2024, https://www.steelonthenet.com/files/automotive.html.

36 Tim Hilditch, Tim de Souza, and Peter Hodgson, "2 - Properties and Automotive Applications of Advanced High-Strength Steels (AHSS)," in *Welding and Joining of Advanced High Strength Steels (AHSS),* ed. Mahadev Shome and Muralidhar Tumuluru (Woodhead Publishing, 2015), 9–28, https://doi.org/10.1016/B978-0-85709-436-0.00002-3.

Figure 3

Body composition for selected vehicle models

Data source: S&P Global Mobility, *AutoTechInsight; BiW Forecast April 2024*. All models shown in the figure refer to the hatchback variant with five doors.

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Figure 4 shows the average shares of steel, aluminum, and other materials used in the vehicle body by major auto manufacturer groups. While steel tends to be the most commonly used material for vehicle body on average, some manufacturers use more aluminum, with the most notable example being Tesla. Aluminum is mostly used for lightweighting purposes, and its use has increased to reduce the fuel consumption of cars.[37] However, substituting steel with aluminum usually requires at least a partial redesign of the vehicle, and several automakers rely instead on higher grades of steel, such as high-strength steel.[38] In addition, steel has a considerably lower cost overall for automakers compared with aluminum.[39]

37 Miklos Tisza and Imre Czinege, "Comparative Study of the Application of Steels and Aluminium in Lightweight Production of Automotive Parts," *International Journal of Lightweight Materials and Manufacture* 1, no. 4 (1 December 2018): 229–38, https://doi.org/10.1016/j.ijlmm.2018.09.001.

38 Tisza and Czinege, "Comparative Study."

39 Mayank Kumar Singh, Application of Steel in Automotive Industry," *International Journal of Emerging Technology and Advanced Engineering* 6, no. 7 (2016): 246–253, https://www.researchgate.net/publication/313900101_Application_of_Steel_in_Automotive_Industry.

Figure 4

Relative average shares of materials used in the vehicle body, by manufacturer

Data source: S&P Global Mobility, *AutoTechInsight; BiW Forecast April 2024.*

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USE OF RECYCLED STEEL IN VEHICLE PRODUCTION

The bulk of steel used in cars is primary steel. In 2022, BMW and Volvo Cars reported using 25% and 15% recycled steel, respectively.[40] The Renault Group estimates that the recycled steel content in its vehicles in 2022 ranged from 17% for flat steel to more than 90% for steel bars and cast iron.[41] Stellantis states that it uses up to 30% recycled steel (pre- and post-consumer), according to their supplier average.[42] Other automakers procure part of their steel needs from suppliers with higher than average recycled steel shares. For example, Mercedes-Benz states that the sheet steel it procures from Steel Dynamics for use in models produced at its Tuscaloosa, Alabama, plant has a recycled steel content of at least 70%.[43]

Some steelmakers have achieved high recycled content in their steel through effective control of scrap sorting and treatment. These include Nucor, which uses 60% recycled content in their automotive-grade flat steel products.[44] Similarly, in 2023, a Swiss Steel Group subsidiary reached a 77% recycled steel share, comprising both pre- and post-consumer scrap, for their stainless steel grades.[45]

END-OF-LIFE VEHICLE HANDLING AND RECYCLING

VEHICLE DISMANTLING AND SHREDDING

End-of-life provisions in EU law direct how vehicles that have reached the end of their useful life are collected and treated.[46] End-of-life vehicles are collected in dismantling facilities and first undergo a parts inventory. All hazardous fluids and materials are then removed from the vehicles, such as oil, brake fluid, coolant, petrol, batteries, components containing mercury, and electronics.[47] These components are treated according to their specific regulation. After depollution, components that have sufficient retained value or that can be recycled are collected, such as catalytic converters, engines, radiators, and transmissions.[48] However, because vehicles are complex products consisting of mixed materials, there is wide variability in terms of the degree of dismantling in different facilities.[49]

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40 Nadja Horn, "BMW Group Sustainability Through Innovation 2022," BMW Group, September 19, 2022, https://www.press.bmwgroup.com/global/article/detail/T0403367EN/bmw-group-sustainability-through-innovation-2022?language=en; Volvo Car Group, *Annual and Sustainability Report 2022* (2022), https://vp272.alertir.com/afw/files/press/volvocar/202303076447-1.pdf.

41 Renault Group, *Universal Registration Document 2022, Including the Annual Financial Report 2022* (2023), https://assets.renaultgroup.com/uploads/2024/10/renault_urd_en.pdf.

42 Chang Shen et al., *The Global Automaker Rating 2023: Who Is Leading the Transition to Electric Vehicles?* (International Council on Clean Transportation, 2024), https://theicct.org/global-automaker-rating-2023. Post-consumer scrap is from end-of-life products, while pre-consumer scrap originates at the steel plants or during the manufacturing of vehicles. See Bo Björkman and Caisa Samuelsson, "Chapter 6 – Recycling of Steel," in *Handbook of Recycling: State-of-the-Art for Practitioners, Analysts, and Scientists*, eds. Ernst Worrell and Markus A. Reuter (Elsevier, 2014), http://dx.doi.org/10.1016/B978-0-12-396459-5.00006-4.

43 Mercedes-Benz Group, "Sustainable Steel Supply Deal for Tuscaloosa," press release, September 18, 2023, https://group.mercedes-benz.com/sustainability/resources-circularity/materials/co2-reduced-steel-tuscaloosa.html.

44 Noah Hanners, Timna Tanners, and Tony Taccone, "Nucor Raw Materials Discussion," presentation accompanying a discussion hosted by Nucor, August 8, 2023, https://assets.ctfassets.net/aax1cfbwhqog/2HTtADt7Svp9XTybwF7W1v/dfe991d5ec0660c9e05c64e498decbef/Raw_Materials_Slides_for_Aug_8_Event_vF.pdf.

45 Helmut Freiherr von Fircks, "Swiss Steel Group Supplies Green Steel Stainless+ for Completely Stainless Steel," press release, Swiss Steel Group, June 19, 2024, https://swisssteel-group.com/en/media/swiss-steel-group-supplies-green-steel-stainless-for-completely-stainless-steel.

46 European Commission, "End-of-Life Vehicles."

47 Valentina-Daniela Bajenaru and Simona-Elena Istriteanu, "Waste from Dismantling of End-of-Life Vehicles," in *International Conference on Reliable Systems Engineering (ICoRSE) – 2024,* ed. Daniela Doina Cioboat (Springer, 2024), https://doi.org/10.1007/978-3-031-70670-7_13; "How We Treat ELVs (End-of-Life Vehicles)," European Group of Automotive Recycling Associations, accessed December 26, 2024, https://egara.eu/.

48 "Infographic: How To Dismantle A Car," Automotive Training Centre, March 4, 2016, https://www.autotrainingcentre.com/blog/infographic-dismantle-car/; Bajenaru and Istriteanu, "Waste."

49 Derek L. Diener and Anne-Marie Tillman, "Scrapping Steel Components for Recycling—Isn't That Good Enough? Seeking Improvements in Automotive Component End-of-Life," *Resources, Conservation and Recycling* 110 (July 2016): 48–60, https://doi.org/10.1016/j.resconrec.2016.03.001.

The remaining vehicle carcass is then crushed into a more transportable size and shredded into small pieces. As all materials are typically shredded together, steel scrap is mixed with other materials, including copper from electrical wiring that is not completely removed in the dismantling phase.[50] The steel scrap is partially separated magnetically from copper and other non-ferrous metals. While these steps reduce the contamination of steel with other materials, the material separation is typically not complete, as copper wires are tightly embedded in the steel frame. [51]

COPPER POLLUTION DURING THE STEEL RECYCLING PROCESS

The next stage in the recycling process involves melting the steel scrap to produce other steel products. When metal scrap is recycled in an electric arc furnace, an electric current is used to melt the scrap. The resulting liquid metal contains all elements that were present in the scrap, including any polluting elements that were not removed beforehand.[52] Minerals are then added, and oxygen is blown though the melted scrap to attract and remove unwanted elements via the slag.

Several of the unwanted elements, such as zinc, mercury, and silver, can be removed by evaporation. Other elements are captured and removed in the slag, such as vanadium and niobium.[53] Some elements remain in the liquid which may cause problems in subsequent steel recycling and production steps. When metals cannot be removed from the EAF melt, these "tramp elements" are considered pollutants.[54] The most common tramp elements are copper, nickel, chromium, molybdenum, and tin.[55]

Of the tramp elements, tungsten, molybdenum, cobalt, and nickel are also used as alloying elements and can be to some extent accommodated in the metal.[56] On the other hand, copper and tin cause small unwanted bubbles and cracks in steel, thus degrading its performance.[57] When the concentration of copper is above 0.1%, it can cause hot shortness, which leads to surface cracks in the downstream hot rolling and forming processes of steel production.[58] Even products with high tolerance for copper contamination typically require a concentration below 0.4%.[59] Tin exacerbates the hot shortness phenomenon at concentrations of 0.04%. However, tin scrap is mainly from packaging, which makes up a much smaller portion of the scrap stream overall and can be removed more easily than copper.[60] Thus, copper contamination is a critical concern, especially for the automotive sector.

Copper tends to accumulate in scrap over subsequent rounds of use and recycling.[61] Over the long term, it is expected that the accumulation of copper in recycled steel

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50 Björkman and Samuelsson, "Recycling"; Daniel R. Cooper et al., "The Potential for Material Circularity and Independence in the U.S. Steel Sector," *Journal of Industrial Ecology* 24, no. 4 (August 2020): 748–62, https://doi.org/10.1111/jiec.12971.

51 Katja Tasala Gradin, Conrad Luttropp, and Anna Björklund, "Investigating Improved Vehicle Dismantling and Fragmentation Technology," *Journal of Cleaner Production* 54 (September 2013): 23–29, https://doi.org/10.1016/j.jclepro.2013.05.023.

52 Allwood et al., *Steel Arising.*

53 Allwood et al., *Steel Arising.*

54 Katrin E. Daehn, André Cabrera Serrenho, and Julian M. Allwood, "How Will Copper Contamination Constrain Future Global Steel Recycling?" *Environmental Science & Technology* 51, no. 11 (June 2017): 6599–6606, https://doi.org/10.1021/acs.est.7b00997.

55 Björkman and Samuelsson, "Recycling"; Total Materia, "Residual Elements in Steel," July 2007, https://www.totalmateria.com/en-us/articles/residual-elements-in-steel/.

56 Allwood et al., *Steel Arising.*

57 Allwood et al., *Steel Arising.*

58 Daehn, Cabrera Serrenho, and Allwood, "Copper Contamination."

59 Allwood et al., *Steel Arising.*

60 Daehn, Cabrera Serrenho, and Allwood, "Copper Contamination."

61 Daryna Panasiuk et al., "International Comparison of Impurities Mixing and Accumulation in Steel Scrap," *Journal of Industrial Ecology* 26, no. 3 (June 2022): 1040–50, https://doi.org/10.1111/jiec.13246.

will make it impossible to reuse in flat products, such as automotive-grade steel, and in high-tolerance steel products, such as reinforcing bars for construction.

End-of-life vehicles are a major source of copper contamination in steel scrap. Some studies report that scrap from end-of-life vehicles presents up to 0.7% of copper concentration, which is too high for even high-tolerance products.[62] As a consequence, although steel has high overall recycling rates globally—with more than 80% of scrap steel being recovered at the end of life—the recovered steel scrap is diluted with higher purity steel and downcycled in products with lower quality requirements than the automotive sector.[63]

APPROACHES FOR HIGH-QUALITY RECOVERY OF AUTOMOTIVE STEEL

The downcycling of recovered steel scrap derives from suboptimal practices in the end-of-life management of vehicles. This does not need to be the case. By adopting best practices in the design, dismantling, and post-shredding phases, copper and other pollutant concentrations can be controlled and significantly reduced.

Increasing the recovery of high-quality steel scrap from end-of-life vehicles implies better control of copper contamination; this effectively means allowing for a better separation of copper and steel during the vehicle recycling process. A precondition for the effective separation of the materials is that vehicles are designed to be easily dismantled and recycled. For instance, wiring could be more easily detachable from the vehicle, thus reducing copper contamination during later recycling phases.[64]

During the recycling process itself, two major approaches can be distinguished: pre- and post-shredding improvements. Pre-shredding improvements involve better separation, often done manually, of steel- and copper-containing parts in the vehicle dismantling phase. The higher value of the recovered steel scrap and the value of the additional copper recovered may compensate for the higher costs of additional dismantling steps, provided adequate remuneration of recovered materials.[65] A recent project by the Institute for Mobilities in Transition (IMT–IDDRI), INDRA Automobile Recycling, Derichebourg Environnement, and ArcelorMittal demonstrated that improved manual copper wire dismantling can reduce copper content in the recovered steel to below 0.1%. This is below the threshold needed for automotive-grade flat steel products.[66] The trial of the recycling of 299 end-of-life vehicles found that this improved dismantling can be economically viable, as the revenue from the additionally recovered copper and the higher value of steel scrap compensate for the higher labor costs.

Post-shredding improvements, in contrast, aim for better separation of high- and low-copper parts after shredding. Once copper is melted together with the scrap steel, however, it is difficult to remove from the metal. Some technologies to reduce copper concentration are already commercially available, such as vacuum melting, where copper is vaporized in a near-vacuum environment, or vacuum arc remelting, which allows the liquid metal to be purified to the requirements of flat steel production.[67] However, these

62 Allwood et al., *Steel Arising.*

63 EU Recycling Industries' Confederation, *Boosting Steel Scrap Recycling in the EU: Debunking Myths & Setting a Clear Pathway to Decarbonise Steel through Recycling* (February 2023), https://euric.org/resource-hub/position-papers/position-paper-boosting-steel-scrap-recycling-in-the-eu-debunking-myths-setting-a-clear-pathway-to-decarbonise-steel-through-recycling; "By-Products, Scrap and the Circular Economy," ArcelorMittal, accessed December26, 2024, https://corporate.arcelormittal.com/sustainability/by-products-scrap-and-the-circular-economy/; Panasiuk et al., 'International Comparison."

64 Daehn, Cabrera Serrenho, and Allwood, "Copper Contamination."

65 Allwood et al., *Steel Arising.*

66 Hannah Gross and Jean-Philippe Hermine, *Steel Car to Car - The Potential of Deep-Dismantling to Decarbonize Automotive Steel Using ELV Steel Scrap* (IMT–IDDRI, 2025).

67 Allwood et al., *Steel Arising.*

processes are energy intensive and not economical.[68] Other technologies have only been tested at a laboratory level and their economic viability is unclear.

Some companies have implemented better post-shredding practices, demonstrating that there is appetite for developing and using new or improved technologies. TSR Recycling demonstrated the technical feasibility of improving post-shredding processes, reaching a copper contamination below 0.08% from post-consumer scrap, which would be low enough to meet the quality requirements of flat steel products used in the automotive sector.[69]

When unable to reach the low copper concentration required by the automotive sector through recycling procedures, steel scrap can also be diluted with primary steel to lower the copper concentration. However, as mentioned above, copper accumulation in steel scrap in subsequent rounds of recycling makes dilution an unsuitable strategy for a more circular use of steel in the automotive sector.

A GROWING POTENTIAL FOR STEEL SCRAP

On a global level, steel scrap availability is expected to increase by more than 50%, from 850 Mt per year in 2023 to 1,300 Mt per year in 2050.[70] With efficient recycling, recycled steel could meet up to half of global steel demand in 2050, up from 35% today.[71] This growth in steel scrap generation could even be enough to meet the entirety of steel demand growth without the need for further expansion of primary steel production.[72]

In the European Union, the availability of steel scrap is projected to reach 130 Mt per year by 2050 from about 120 Mt per year in 2020.[73] However, this scrap is often of poor quality. In Western Europe, the average copper content in recycled steel is 0.29%, which results largely from copper-contaminated automotive scrap, waste electrical and electronic equipment, and demolition waste.[74] The European Union, therefore, faces an oversupply of low-quality steel scrap, a situation that is expected to worsen in the future.[75]

The European Union consumed approximately 75 Mt of steel scrap in 2023, imported 4 Mt, and exported 19 Mt. Exports have risen by 50% over the past decade, which partly reflects the shift toward flat steel products, which require higher-quality inputs.[76] The quality of EU-generated steel scrap has been declining, and it is forecasted that after the mid-2020s, steel scrap with impurities higher than 0.35% will dominate.[77] Consequently, EU scrap exports primarily consist of low-purity material. Considering the projected increase in steel scrap generation, even if more scrap is used in the EU economy, it will not change the overall export trend.

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68 Allwood et al., *Steel Arising.*

69 "Products for a Green Future That is Already Here Today," TSR Recycling, accessed February 12, 2024, https://www.tsr.eu/en/products/overview/.

70 Çiftçi, "Future."

71 World Steel Association, *Scrap Use*.

72 Allwood et al., *Steel Arising*.

73 Dworak, Rechberger, and Fellner, "Tramp Elements."

74 Yasaman Nazari Marzijarani, "Investigation on the Impact of Increasing the Recycled Steel Content of a Car Body from a Materials Properties Perspective: A Case Study at Volvo Cars Corporation" (master's thesis, Uppsala University, 2023), https://uu.diva-portal.org/smash/get/diva2:1789719/FULLTEXT01.pdf; Panasiuk et al., "International Comparison."

75 Leon Rostek et al., *A Dynamic Material Flow Model for the European Steel Cycle* (Fraunhofer ISI, 2022), https://doi.org/10.24406/PUBLICA-58.

76 Eurofer, "European Steel in Figures 2024."

77 Dworak, Rechberger, and Fellner, "Tramp Elements"; Dworak and Fellner, "Steel Scrap."

In 2023, the European Union exported steel scrap to Türkiye—by far the largest importer of EU steel scrap—Egypt, India, and Pakistan.[78] Emerging economies are expected to reduce their demand for imported scrap as they develop their own internal supply of recycled steel, leaving the European Union with a surplus of low-purity scrap that will be hard to use without efforts to improve its quality. With scrap generation on the rise in the European Union and globally accompanied by a gradual decrease in scrap quality, changes in international steel scrap flows are anticipated regardless of policy shifts. Overall, considering the growing availability of steel scrap in the European Union and in countries to which the European Union exports steel scrap, increasing the use of recycled steel in the automotive sector is unlikely to divert material from the domestic construction sector or exports.

POLICY APPROACHES TO A MORE CIRCULAR USE OF AUTOMOTIVE STEEL

A more circular use of automotive steel in the European Union faces challenges at several points in the vehicle life cycle. This section presents policy approaches that could contribute to overcoming them.

COLLECTION OF VEHICLES AT END OF LIFE

In 2022, 12.5 million new passenger cars and light commercial vehicles were produced in the European Union and 4.7 million end-of-life vehicles were collected that same year.[79] This difference partly stems from the documented export of used vehicles outside the European Union and from vehicles of unknown whereabouts. The latter include vehicles for which no information is available regarding whether they were exported, illegally dismantled, or abandoned. While there is significant uncertainty regarding the number of vehicles of unknown whereabouts, they are estimated to number 3–4 million annually.[80] As noted in the European Commission's report accompanying the proposed regulation on circularity requirements and end-of-life vehicles, the collection of vehicles of unknown whereabouts could be improved with improved exchange of information on the registration and deregistration of vehicles and efforts to better distinguish between used and end-of-life vehicles.[81]

PREVENTING QUALITY LOSS OF AUTOMOTIVE STEEL AND IMPROVING STEEL CIRCULARITY

As discussed above, vehicle recycling currently results the downcycling of high-quality automotive steel to low-quality steel scrap. In particular, copper contamination during vehicle recycling makes recycled steel from end-of-life vehicles unsuitable to meet the quality requirements of automotive applications. This can be mitigated by better

78 Corey Aunger and Katya Ourakova, "EU Steelmakers Ask for Scrap Export Curbs," *Argus Media*, November 12, 2024, https://www.argusmedia.com/en/news-and-insights/latest-market-news/2627874-eu-steelmakers-ask-for-scrap-export-curbs.

79 European Automobile Manufacturers' Association (ACEA), "EU Passenger Car Production," May 1, 2023, https://www.acea.auto/figure/eu-passenger-car-production/; ACEA, "EU Commercial Vehicle Production," May 1, 2023, https://www.acea.auto/figure/eu-commercial-vehicle-production/; Eurostat, *End-of-Life Vehicle Statistics,* accessed February 12, 2025, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=End-of-life_vehicle_statistics.

80 Directorate-General for Environment (European Commission) and Oeko-Institut e.V., *Assessment of the Implementation of Directive 2000/53/EU on End-of-Life Vehicles (the ELV Directive) with Emphasis on the End of Life Vehicles of Unknown Whereabouts: Under the Framework Contract : Assistance to the Commission on Technical, Socio Economic and Cost Benefit Assessments Related to the Implementation and Further Development of EU Waste Legislation.* (Publications Office of the European Union, 2018), https://data.europa.eu/doi/10.2779/446025.

81 European Commission, *Commission Staff Working Document: Impact Assessment Report Accompanying the Document 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,* SWD/2023/256 final (2023), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2023%3A256%3AFIN.

copper separation from steel, either during dismantling or after the shredding process. Compared to a copper content of 0.7% from current vehicle recycling practices, both approaches have been demonstrated to enable the recovery of automotive steel with a copper content of below 0.1%.

Several policy approaches can help facilitate and incentivize improved vehicle recycling processes and steel recovery:

Vehicle design. A precondition for an effective separation of the materials is designing the vehicle to facilitate easier recycling. For example, designing vehicles so that copper-containing parts are easily removable facilitates dismantling and avoids contamination among materials.

Closed-loop recycled steel quota. Requiring that new vehicles sold in the European Union meet a recycled steel content target, as discussed in the Commission's proposal for a regulation on circularity requirements for vehicle design and management of end-of-life vehicles, could create a market for a better recovery of steel from cars.[82]

To ensure that this results in an additional availability of high-quality steel scrap, however, it is important that the recycled steel eligible to be used under this quota is sourced from end-of-life vehicles. A generic, open-loop recycled steel quota without such a specification does not necessarily incentivize better recycling of vehicles, as it could also be met from the recovery of steel from the recycling of other products. Therefore, it entails the risk of diverting recycled steel from other uses.

We next estimate how high a closed-loop recycled steel quota could be. Table 1 shows the yearly production of passenger cars and light commercial vehicles in the European Union, as well as the number of end-of-life vehicles collected, from 2018 to 2022.[83]

Table 1
Number of passenger cars and light commercial vehicles produced and collected at the end of life in the European Union (million vehicles)

	2018	2019	2020	2021	2022
Passenger cars produced	14.6	14.1	10.8	10.1	10.9
Vans produced	1.2	2.2	1.7	1.7	1.6
Total production	**15.9**	**16.2**	**12.5**	**11.8**	**12.5**
End-of-life vehicles collected	6.1	6.1	5.4	5.7	4.7
Feasible closed-loop recycled steel content	32%	31%	35%	39%	31%

We assume that only the steel in the body-in-white and chassis is recycled, thus excluding all other steel-containing components in cars. While the average mass of cars was 21% smaller 20 years ago, the mass share of steel in vehicles was about 20% higher than for today's vehicles.[84] This means that the average steel content of a typical EU passenger car produced today can be assumed to be the same as in 20-year old end-of-life vehicles. Assuming a production-weighted average of 434 kg of steel for the body-in-white of passenger cars and vans, and that the body and chassis of vehicles

82 European Commission, Proposal for a Regulation on Circularity Requirements for Vehicle Design and on Management of End-of-Life Vehicles.

83 ACEA, "EU Passenger Car Production"; ACEA, "EU Commercial Vehicle Production"; Eurostat, *End-of-Life Vehicle Statistics*.

84 Monteforte, Mock, and Tietge, *Vehicle Market Statistics*; Bui et al., *Technologies.*

represent 60% and 30%, respectively,[85] this translates into an average of 650 kg of steel potentially recovered from an average vehicle's body and chassis. Adding a 9% material loss during recycling, these end-of-life vehicles represented a theoretical steel recovery potential of 592 kg per vehicle.[86] For new vehicles, including the 10% of steel used in parts other than the body and chassis, the steel requirement for production is estimated to be 722 kg per vehicle.

Based on these considerations, and the number of vehicles produced and collected at their end of life between 2018 and 2022, we can estimate the recycled steel quota that could be supported with a closed-loop requirement, assuming ideal recycling of the steel contained in the body and chassis. As presented in Table 1, this feasible closed-loop recycled steel quota varied between 32% in 2018 and 39% in 2021, with an average of 34%. Based on this assessment, we thus conclude that a closed loop recycled steel quota of 30% can be feasible.

The European Commission, for its part, considered a recycled content target of 25%–30% for newly type-approved vehicles in its impact assessment accompanying its regulatory proposal.[87] To provide enough lead time for vehicle recycling, steel production, and vehicle manufacturing to establish a better recovery of automotive steel and material flows, a recycled steel quota could initially be set at a low level and increased over time.

Separated quality standards for steel scrap. In parallel, and to support coordination between actors in the recycled steel supply chain, a new steel scrap standard could be introduced. Current EU standards for shredded steel scrap require copper and tin contents below 0.25% and 0.20%, respectively.[88] These levels are unsuitable for automotive applications without dilution. A potential policy could define stricter standards for high-quality scrap with lower pollutant thresholds, achieved through advanced dismantling and purification processes. Such scrap could receive a premium label and remuneration, incentivizing improved recycling practices.

Supporting the decarbonizing of steel production with EU Emission Trading System (ETS) CO_2 pricing. The ETS is a cap-and-trade system, whereby a cap is set for emissions of included sectors and companies can trade emissions allowances. The continuous reduction of free allowances in the EU ETS increases the pressure on the steel sector to reduce CO_2 emissions. As the production of recycled steel is less GHG emissions-intensive than primary steel production—and cheaper than switching to the green hydrogen DRI-EAF pathway for low carbon primary steel production—the EU ETS creates a long-term incentive for increasing the use of recycled steel in the economy. Given the coordination and investment requirements across the companies involved in vehicle production, recycling, and the recycled steel supply chains, the price signal of the EU ETS might not be strong enough to increase availability of steel scrap. Mandating the use of recycled steel coming from end-of-life vehicles can be helpful to establish this coordination and long-term planning.

CONCLUSIONS

A transition toward a more circular use of automotive steel presents the opportunity to reduce the environmental impact of primary steel production at comparably low cost while also reducing the European Union's dependency on iron ore, copper, and coking

85 Argonne National Laboratory, *GREET,* October 2022.

86 Allwood et al., *Steel Arising*.

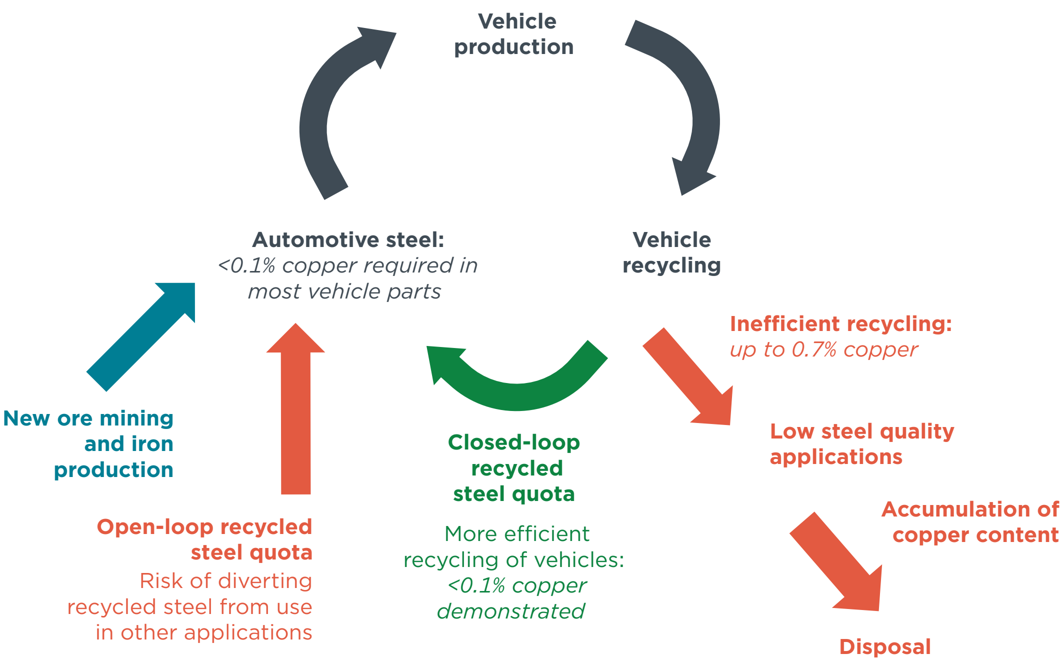
87 European Commission, *Impact Assessment Report.*

88 European Ferrous Recovery and Recycling Federation, *EU-27 Steel Scrap Specification* (2007), https://www.mgg-recycling.com/wp-content/uploads/2013/06/EFR_EU27_steel_scrap_specification.pdf.

coal imports required for primary steel. Partially replacing the use of primary steel produced through the BF-BOF pathway by a 30% share of recycled steel, for instance, reduces the GHG emissions of producing a typical EU passenger car by 0.4 tonnes of CO_2e per tonne of steel, a 20% reduction in steel-related emissions. With 12.5 million vehicles being sold in the EU in 2022, these savings would accumulate to 3.7 million tonnes of CO_2e.

Figure 5 illustrates that a more circular use of automotive steel is determined by the recovery of high-quality steel from end-of-life vehicles, its use in the production of new vehicles, and the interconnection of recycled steel flows between the automotive industry and other sectors. The flow of automotive steel is currently characterized by high quality requirements at the point of vehicle production—in particular, a concentration of copper below 0.1%—and a poor quality of steel scrap recovered from the recycling of end-of-life vehicles. This downcycling stems from the pollution of automotive steel with copper wires during the recycling, leading to an estimated copper content in the scrap of up to 0.7%. Without dilution with high amounts of primary steel, the steel recovered from vehicle recycling cannot be used again for vehicle production and is instead used in applications with lower quality requirements, such as construction. In successive rounds of recycling, the copper content increases, rendering steel scrap unsuitable even for high-tolerance applications and resulting in its disposal. At the point of production, the high-quality requirement of automotive steel is met with a disproportionately high share of primary steel, almost entirely produced from the GHG emissions-intensive BF-BOF pathway, resulting in an emissions intensity of automotive steel higher than the steel industry average.

Figure 5
Schematic of the current flow of automotive steel and expected impact from an open-loop and a closed-loop recycled steel quota



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With its proposal for a regulation on circularity requirements for vehicle design and management of end-of-life vehicles, the European Commission aims to increase the circular use of automotive steel and proposes to conduct a feasibility study to inform a recycled steel quota for new vehicles. As we argue in this brief, a closed-loop recycled steel quota requiring the use of steel recovered from the recycling of end-of-life vehicles can ensure an effective reduction in the use of primary steel. An open-loop recycled steel quota that is not restricted to using steel from end-of-life vehicles, in contrast, entails the risk of diverting recycled steel use from other applications. In effect, such a quota might fail to avoid the downcycling of automotive steel and not result in additional and longer availability of recycled steel in the broader economy.

If the recycled steel quota were limited to the use of steel recovered from end-of-life vehicles, in contrast, it would directly incentivize improvements to the vehicle recycling process. It has been demonstrated that improved manual removal of copper wires during vehicle dismantling can reduce the copper content in end-of-life vehicle scrap to below 0.1%, which is low enough to qualify for use in automotive steel. The increased recovery of copper from such improved processes may suffice to balance the higher costs. In addition, improvements in scrap treatment after the shredding process have been demonstrated to achieve similar amounts of low copper content. If all end-of-life vehicles scrapped in the European Union were to be treated with such processes—so that the steel contained in the body and chassis were completely recovered and recycled—this recovered steel could support a closed-loop recycled steel quota for new car production of up to 30%. To provide enough lead time for the vehicle recycling, steel production, and vehicle manufacturing industries to establish a better recovery of automotive steel and material flows, the quota could be set initially at a low level and gradually raised.

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