Executive Summary

Being committed to the global climate targets, the European iron and steel industry aims to reduce its production-related CO_2 emissions by at least 50% compared to 1990 levels until 2030 with the goal of climate neutrality (no net emission) by 2050. Scrap is a major secondary raw material in the steelmaking process and an important pillar towards a CO_2-lean steel industry. Melting steel scrap leads to lower resource consumption than steel production via the primary production route and therefore holds environmental and economic advantages. A prerequisite for recycling scrap and thus its recirculation to the metallurgical process is the availability of high-quality scrap and comprehensive knowledge of its composition. In particular, post-consumer scrap often cannot meet the required quality criteria (e.g., share of non-metallic components or non-ferrous metals).

Within the framework of the interdisciplinary R&D project IRONER, financed by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BKM) and coordinated by the Austrian Research Promotion Agency (FFG), potentials to optimise sustainable scrap recycling in Austria were examined. This involved a quantitative and a qualitative determination of scrap availability by means of a material flow analysis and material pinch analysis. The obtained findings were validated by stakeholder surveys. These surveys provided additionally insights into the industry's need for innovation. Furthermore, metallurgical and materials engineering related considerations were elaborated and summarised.

The Austrian steel industry has one of the highest steel production per capita in the world (AT: 0.9 t/year/capita, EU: 0.35 t/year/capita, worldwide: 0.25 t/year/capita) and holds a sophisticated steel product portfolio (EUROFER, 2021, p.14-16). This consists mainly of flat products that require a high degree of purity of the resources employed. Consequently, the intended increased use of scrap for steel production poses a particular challenge.

In 2021, Austria's steel production accounted for almost 8 million ton (World Steel Association, 2022, p.9). Thereby, about 1.5 million tons of scrap were processed, with the share of imported scrap being 58% and the share of domestic scrap being 42%. These 1.5 million tons of scrap include the quantities supplied by the scrap market, while excluding production scrap of the steel producers. The future demand for scrap is estimated to increase by 10% to 15% over the next 3 years and by 70% to 100% over the next 5 to 10 years. The scrap market currently estimates the annual scrap volume in Austria at approximately 2 million tons, whereas approximately 1 million ton are exported, and 960 tons are imported, thereby keeping imports and exports almost in balance in terms of volume. (data derived from stakeholder interviews, 2022)

In order to gain a deeper understanding of scrap availability in Austria, material pinch analyses (based on (Dworak und Fellner, 2021, p.105692; Dworak et al., 2022, p.106072)) were carried out considering three different scenarios. Scenario 3 assumes that new scrap is traded across borders (mainly imported) and when it comes to end-of-life scrap, only the quantities generated in Austria are taken into account, thereby resulting in a scrap volume of almost 3 million tons. These quantities are sufficient to account for about 35% of the steel demand. Within scenario 1 and 2, it is assumed that the European scrap volume accounts for about 65% of the European crude steel demand. Due to the high per capita steel production within Austria, this results in a higher availability of scrap (approximately 5 million tons). The use of these resources would increase the

scrap valorization rate accordingly. As the quality of the scrap is a limiting factor in scrap recycling, two possibilities are considered in the analysis. The first option involves the mixing and contamination of the scrap fractions, as currently observed. The second possibility is the theoretical potential of complete sorting. The investigated scenarios indicate that Austria should be able to increase scrap availability from the current 35% (referred to steel production) to 63%, provided that the scrap can be processed to such an extent that it can also be used for the produced steel quality. This scrap availability would increase to 67% by 2030 and even to 75% by 2050 in relation to crude steel production, thus showing great potential in the further development of a suitable scrap recycling system.

Current processing and sorting techniques are at their limits, especially with increasingly complex products. Therefore, actions to improve scrap sorting are inevitable in order to achieve the required separation degrees. This raises major challenges for the processing and recovery of materials, from a logistical as well as a technical point of view. Only by including the entire process chain (value chain, comprising scrap recycling companies, plant manufacturers and steel producers) is it possible to meaningfully define and implement the necessary innovations to increase steel recycling. Important aspects are the area-wide collection and processing of scrap, the separation and processing of complex composite materials, the guarantee of alloy-specific separation and the digitalisation of processes in the steel recycling industry as well as in the steel plant. The use of innovative technologies for processing and sorting, as well as their combination, can significantly improve scrap quality and sorting purity and thus ensure scrap availability for domestic consumption. Therefore, it is essential to advance the further development, testing and integration of analytical methods to identify the impurities present in the scrap and effectively remove these scraps before feeding the furnaces. Sensor-supported sorting, automated dismantling of waste as well as the digitalisation of processes are promising approaches to increasing the use of scrap.

Starting from the stakeholder survey, the effect of the accompanying elements copper, nickel, molybdenum, tin, arsenic, antimony and lead on the metallurgical process was assessed and their impact on the transformation behaviour as well as their effect on various steel grades (e.g., deep-drawing grades, electrical steel, tubular steels and case-hardened steels) was studied. Accompanying elements can have negative as well as positive effects on the steel properties, whereby the negative ones prevail. Continuing research on materials properties for a better understanding of the interaction of these elements with each other, but also on the performance characteristics of steels, is necessary. Whether and to what extent the accompanying elements actually have to be restricted to today's usual limits, and the development of novel steel grades with greater tolerance to these elements, are also major research and development objectives in this context.

The removal of many accompanying elements is difficult or even impossible within the conventional steelmaking routes employed today, making it necessary to dilute the iron with pig iron or directly reduced iron (DRI or hot briquetted iron (HBI)) in order to achieve the requested levels. Consequently, an accumulation of these elements especially in low quality scrap is to be expected, requiring intensified research on their behaviour in the steel melt as well as on their effects in the finished product. The elements pose difficulties during casting by lowering the liquidus temperatures and additionally lead to changes in the surface properties.

From a metallurgical point of view, the increasing use of secondary raw materials and the associated accompanying elements result in changes in process control as well as a need for additional research with regard to already well-studied reactions and interactions. Therefore, their effects on specific steel grades need to be studied and described individually. However, the most efficient approach is better separation technologies to avoid unwanted elements entering the production process.

The significance of increased use of scrap for climate protection, competitiveness and economic development is made clear by the scarcity of the greenhouse gas budget available to meet the Paris climate targets (according to the IPCC report (IPCC, 2021, p.3-146), the greenhouse gas budget will be exhausted by 2030 if CO_2 emissions continue as they are now) and the currently limited access to more climate-friendly renewable energy sources. Steel scrap is a valuable raw material, not only because of its iron content, but also due to energy that can be preserved by its recycling. By melting and recycling scrap in an electric arc furnace (100% scrap), approximately 80% of primary energy as well as CO_2 emissions can be saved compared to the integrated route.

A main objective of the research is to estimate the direct and indirect economic effects of increased scrap use by means of a scenario analysis based on the operating costs and investment requirements for increased scrap use in combination with climate-neutral options for primary production, whereby a working hypothesis is that climate-neutral development in the steel sector through increased scrap use should not only be more efficient overall and thus cheaper, but also more resilient, as supply chains can be diversified.

An inventory of scrap qualities and distribution as well as a technology screening form an excellent basis for further R&D activities to increase steel recycling. Nationally funded flagship projects involving all actors along the scrap processing chain are a necessity to demonstrate increased scrap value creation. This includes the removal of impurities in combination with more efficient scrap yard management (characterisation, sorting) and processing into quality steel products. Only then it will be possible to ensure competitiveness and sustainability in Austria in the long term.

Overall, there is a need for comprehensive, interdisciplinary and funded R&D projects that address the following topics on an industrial scale (i.e., with a technology maturity level TRL of 8 at the end of the project; fully developed in terms of system technology):

- Optimised analytical methods and sorting technologies implemented at the scrap yard (at the scrap processor and at the steel plant) and increased throughput and fast processing capability of spectroscopic scrap characterisation methods
- Combination of optical and spectroscopic scrap analysis
- Adjustment of the scrap processing plant to increase/optimise the separation of non-metallic components (e.g. plastics) and to separate ferrous and non-ferrous metals
- Improved data availability
- Activities closing the gap in the recycling of end-of-life vehicles in Austria (as part of a comprehensive recycling concept within the framework of a funding project)
- Detailed research concerning the metallurgical and material characteristics of accompanying elements - development of steel grades with higher tolerance regarding accompanying elements

- Overall project objective of increased scrap value creation, i.e., combining methods for the removal of impurities with a more efficient management of the scrap charging mix for subsequent processing into high-quality steel products
- Communication activities along the value chain (scrap recyclers/plant manufacturers/steel producers) and increase public acceptance by demonstrating the need to implement measures to increase recycling of scrap and minimise exports

References

EUROFER: European Steel in Figures 2021, 2021.

World Steel Association: World Steel in Figures 2022, 2022.

Dworak S., Fellner J.: Steel scrap generation in the EU-28 since 1946 – Sources and composition. In: *Resources, Conservation and Recycling* 173, p.105692, 2021.

Dworak S., Rechberger H., Fellner J.: 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. In: *Resources, Conservation and Recycling* 179, p.106072, 2022.

IPCC: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021.