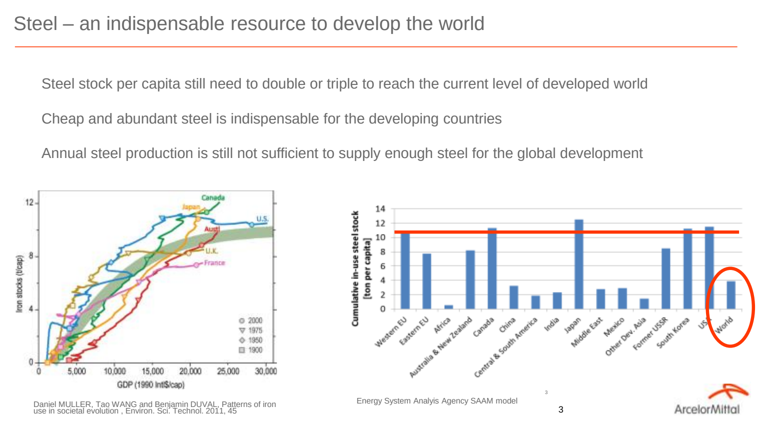
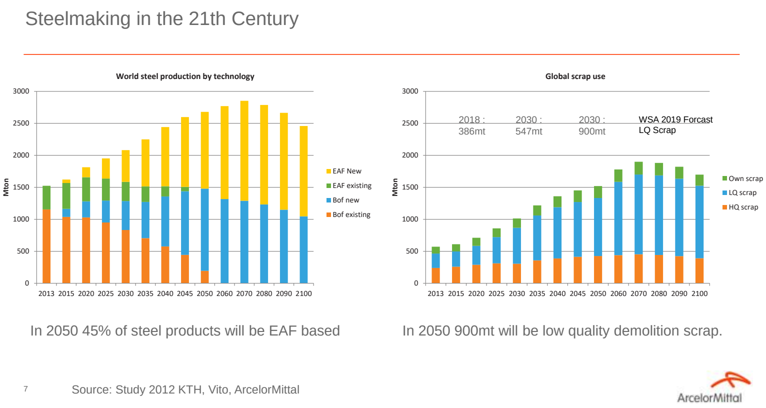
Green steel by EAF route: a sustainable value chain in the EU Circular Economy scenario

Opening plenary section – Outcome of the presentation content and discussion

Steel is and will continue to be an indispensable material for society due to its characteristics such as recyclability, durability and versatility. These properties make it a material "permanently" available to future generations. Even during the expected transition of the energy sector towards renewable sources, steel will continue to have a role to play. Publicly available information confirms that the steel stock worldwide has to increase twice or three times, in order to allow developing countries reaching the living standards of the developed regions.

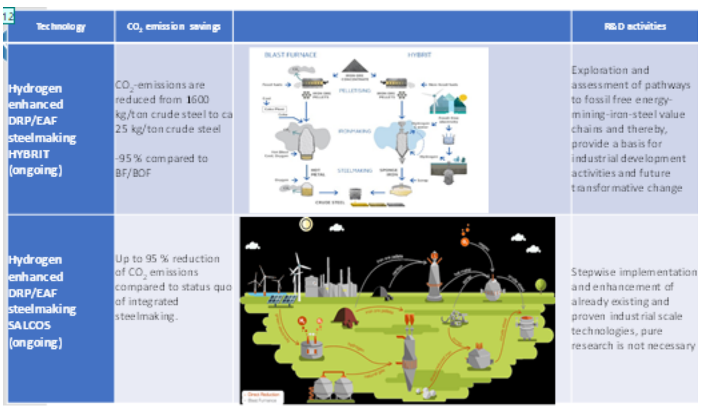
In this context, the steel production by electric arc furnace (EAF) represents worldwide 28% of the total and reaches 46% in Europe, according to 2017 data from scr. Moreover, the share of the global steel production by EAF route is expected to reach, and probably overpass, 45% worldwide. This transition will most likely start from 2030 onward: when the steel production, usually market driven, will become technology and climate-neutral driven.





The steel production actually works through a profound synergy between the primary route, using mostly virgin raw materials and a limited amount of scrap, and the secondary route, using essentially ferrous scrap, will find new symbioses and technological configurations, in which the two production routes will continue to find a synergic approach.

Iron ore and scrap routes must be in symbiosis: the main % of carbon steel long products in the EU (79%) is produced by EAF, while 96% of flat is product by blast furnace (BF). Low Carbon Future RFCS reports that in a future view, the two steel production routes (from iron ore and from scrap) may share the utilization of EAF. Ongoing projects are related to green steel production by Direct Reduction, Integration (DRI) of renewable electricity and hydrogen production (as SALCOS and HYBRIT projects)

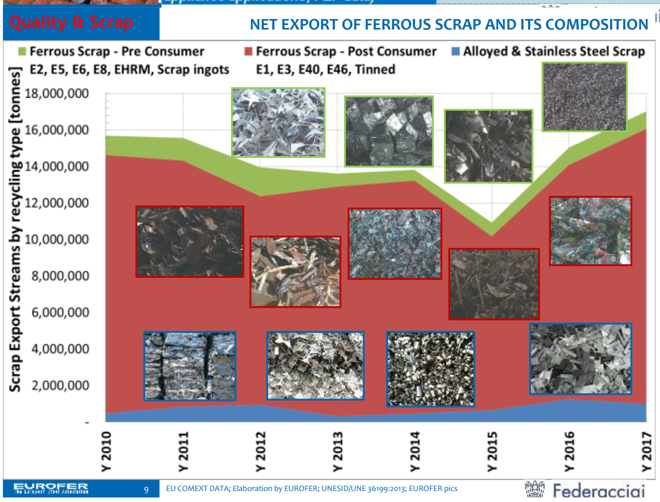


Therefore, within this scenario, many opportunities might materialize for the

EAF steel production route; opportunities that can be taken only by solving issues already (or to be still) identified and undertaking medium- and long-term strategies. Whatever will be the path towards decarbonisation and thus sustainability of the steel production globally, it has to follow technologies and solutions that need three requisites: **affordable, scalable and circular.**

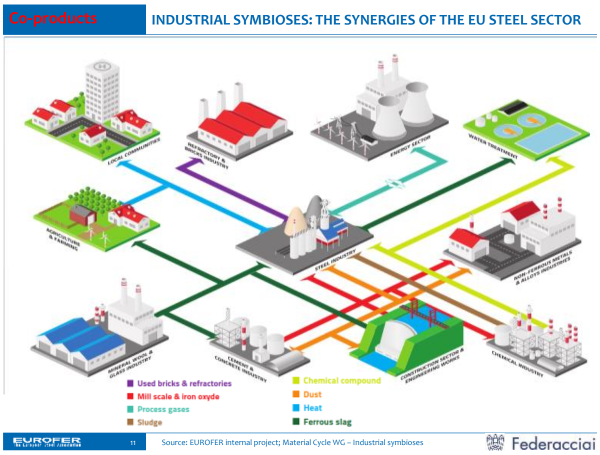
Among the different aspects discussed during the session, a certain number of topics emerged as worthy of consideration.

EUROFER EPD Project - (2013) - EoL Evaluation EU Average	% Reused	% Recycled	% Lost
Heavy Structural Sections/tubes	13.3	86.4	0.4
Rebar (in concrete super structure)	0.0	76.3	23.7
Rebar (in concrete sub-structure or foundations)	0.5	67.8	31.7
Steel piles (sheet or bearing)	16.4	65.4	18.2
Light structural steel (e.g. galvanised purlin, supports etc.)	4.4	81.0	14.6
Profiled sheet cladding (roof / façade)	8.9	85.0	6.2
Internal light steel (e.g. plaster profiles, door frames)	4.0	84.1	11.9
Other (e.g. stainless steel - if different from above)	3.4	96.0	0.6
Hot Rolled Coils (metal sheet for building applications; PEF data)	-	95.0	5.0
Hot Rolled Coils (metal sheet for appliance applications; PEF data)	-	90.0	10.0



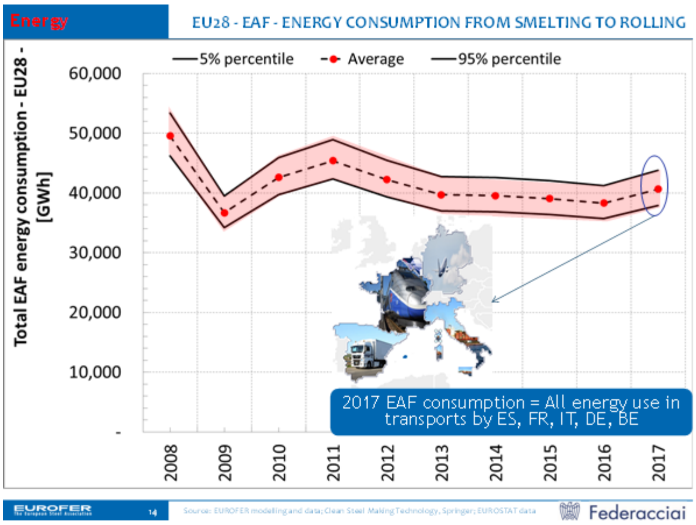
The first one is the concept of the "**2050 scrap blending wall**". Although ferrous scrap will be part of the future strategies for reducing green-house gas emissions, there are still limitations linked to the availability of scrap with the right quality. The presence of tramp elements such as non-ferrous metals might limit the use of ferrous scrap for production of certain steel grades. Therefore, *scrap treatments, processing and cleaning*, will be an opportunity linked to the recovery of certain non-ferrous fractions, such as tin, copper and zinc. This path, if properly developed, can realise a win-win situation. The scrap treatment sector might afford increasing the ferrous scrap quality and being even more profitable and the steel sector might utilise more ferrous scrap quantities in many more steel qualities. *Research efforts on this topic are necessary because valorisation of low-quality scrap streams is one of the key elements for fostering a green transition of the steel production as a whole.*

The second one is the concept of "**industrial symbiosis**". Every material stream (residue) generated together with steel has to find its proper fate, to be re-used, recycled or recovered. The valorisation of the industrial residues is an important step towards the full circularity of the steel sector. Although steel is a circular material in itself, the steel sector is not yet because more research efforts are necessary for conditioning the properties of the residues, for identifying more final uses which are appropriate and for mitigating the risks of over demanding legislations. Industrial residues from EAF steel production have been successfully used in the past by other sectors but new EU legislations or more stringent EU member states laws might endanger good practices and then the level of circularity reached by the steel sector. Therefore, *research efforts should focus on how to identify additional applications for residuals streams (slag, dust, sludge) from EAF, in order to lower the impacts of unintended consequences by*



new legislations or by more stringent controls, in full respect of environmental safety and human health.

The last theme that emerged as important for having a fully sustainable production of steel in the future is the "**electricity availability**". The path towards carbon-neutrality and to sustainability of many EU industrial sectors focuses on using more and more electricity as energy carrier. Thus, energy savings, efficiency and optimal use of electricity will be crucial in the future. EAF steel production at the EU 28 level, utilises on average 40,000 GWh of energy annually. Taking into account the predicted growth of the steel production by EAF-technology, energy sources such as electricity will become more and more strategic. *Thus, research efforts towards energy efficiency and optimised use of electricity are of primary importance.*



Following the plenary session, four parallel technical sessions were focused on scrap management, decarbonisation, energy efficiency and circular economy. These sessions explored in more detail, within a decarbonisation and circular economy framework, the themes identified in the plenary session.

Scrap management Session - Chairman A. Schweiger

The presentations given in this session showed final or interim research and development results on the following items: scrap yard management; influence of scrap quality on the environmental performance of steel production; metal scrap classification and tracking; sustainable and flexible EAF production. The content of the presentations and the discussion highlighted the following key aspects.

The ferrous scrap accounts actually for 60% of the costs of EAF steelmaking process. However, there is still a huge room for **improving the operations within the steelmaking scrap yard facilities**. In particular, a better tracking of the different scrap grades and of their properties has a big potential on reducing costs and improving performances. Techniques based on directly and indirectly assessing ferrous scrap properties allows to adapt optimal scrap grades blend for reducing the environmental footprint of the EAF steel production site. Thus, as a general consequence, the upgrade of the scrap qualities and their improved management within an installation will create additional opportunities for pushing further down the overall impact of steel productions in EAF. This strategy might be made more effective and more robust in giving positive outcomes using adaptive dynamic techniques for controlling the EAF process and improving yields during the different production steps. Testing the use of new digital tools and artificial intelligence can have a positive contribution and may open new research paths to be explored and possibly proficiently exploited.

Decarbonisation - Chairman K. Peters

The presentations given in this session showed final or interim research and development results on the following items: dynamic tools and advanced sensors for EAF process control; substitution of fossil fuel with H_2 for substantial reduction of CO_2 in the EAF steel route; reduction of direct

CO_2 emissions in the EAF by substitution of fossil coal with biogenic materials; innovative and flexible route for production of virgin iron units in a route with very low or null GHG impact. The content of the presentations and the discussion highlighted the following key aspects.

EAF steelmakers are today called to further optimize their processes by reducing the operating costs, managing the discontinuity of quality and price of scrap and raw materials, and increasing the flexibility of production. This must be coupled with profit margins and the environmental performance. Examples and results of the application of the most recent process control technologies to reach these goals have been presented, such as automatic EAF, automatic scrap yard, energy management systems. In parallel to **process optimisation**, the effects of the current trend in the reduction of carbon intensity of electric energy, together with technical solutions to replace carbon and NG with biomass and hydrogen has been analysed. **The potential of Direct Carbon Avoidance (CDA) will likely bring this route to near zero net emissions within the next 20 years.** The increasing cost for purchasing CO_2 allowances could make the investment economically convenient.

In the case of green H_2 produced by electrolysis, the parameter that influences the economical evaluation is the availability and the cost of renewable electric energy. Having electric energy available at cost <30€/MWh would make the investment viable. A possible option is the hydrogen production by catalytic Plasma technology that has a better energy balance than electrolysis. However, the process is characterized by a lower efficiency in terms of CO_2 emissions (30%). **Further investigations and development efforts are necessary to improve the performance and reduce the cost of technologies for H_2 production.**

The feasibility of biomass utilization in EAF has been studied in the RFCS project GREENEAF2. Hundreds of heats have been carried out replacing partially and totally the lump fossil coal charged in the basket and confirmed the **possibility to use biogenic material to reduce direct EAF CO_2 emissions (up to 70%), without significant modification in steel and slag analysis.** Supplementary stack analyses have been also performed to quantify environmental effects, but did not show any negative influence of the utilization of biochar and biomass to substitute fossil coal. However, **biochar material is currently not sufficiently available in Europe.** In addition, **R&D is necessary to allow also replacing the pulverised carbon injected in EAF**.

The presentation pointed out that in this scenario, to compensate the envisioned degradation of steel scrap quality, a significant influx of virgin iron units will be necessary together with the development of technologies enabling to remove the tramp elements and stabilization of the quality of steel used in the world. However, there are limits though to the expansion of this route: availability of high-grade pellets with gangue of 5% or less is rather limited, and cost is high. And it is hard to imagine a near future where 500Mt of DR-grade pellets will be available as the quality of the iron ore sources worsens gradually. EAF and its development will play an important role in **a nearly carbon-neutral ironmaking route able to overcome the limitations in availability of premium grade pellets, and allowing simplified, gradual introduction into an existing ironmaking facility is necessary.**

Energy efficiency - Chairman B. Kleimt

The presentations given in this session showed final or interim research and development results on the following items: energy efficiency principles applied for making EAF steel production greener and more sustainable; recovery of the waste energy from off-gases and slag; advanced assessment techniques of energetic and environmental performances. The content of the presentations and the discussion highlighted the following key aspects.

Energy losses through heat dispersion are still a relevant part of the inefficiencies of the EAF process. About 25% of the total energy losses in the EAF process are due to sensible heat and chemical energy losses via the EAF off-gas. Technologies to **recover these energy losses via heat exchangers for steam generation to be used directly in the steel plant, for district heating or**

for electricity production are available and already applied on industrial scale. The return of the investment (ROI) time of these techniques will decrease in the future with increasing prices for emission certificates. Most likely, in the future, the steam produced with this heat recovery technology could be used for directly producing hydrogen via electrolysis. Another dispersion outlet of waste energy in EAF steelmaking is represented by the ferrous slag, during its solidification phase. Technological problems to recover this waste heat have not yet been solved, but are currently investigated on pilot and research level. However, the potential energy savings coming from the recovery of slag heat will not be as high as the ones from EAF off-gases. It has been also underlined that the final quality of the ferrous slag in terms of reusability may not be affected by the use of such heat recovery processes. Furthermore, different monitoring, simulation and analysis techniques of the EAF production processes have been presented and discussed during the session. It is actually possible to simulate heat recovery processes and techniques in order to identify different heat recovery solutions and this will help in investigating feasibility and effectiveness in relation to the particular EAF installation. Moreover, all presentations clearly demonstrated that the **waste heat recovery and more broadly the different practices to increase energy efficiency have a very high potential in decreasing the footprint of EAF steel production.**

Circular Economy - Chairman E. Malfa

The presentations given in this session showed final or interim research and development results on the following items: the utilisation of alternative input materials, such as tyres and polymers, in steel production; the recycling of dusts; the valorisation of the EAF slag as a polymer and of the secondary metallurgy slag. The content of the presentations and the discussion highlighted the following key aspects.

Various **examples of the use of secondary raw materials by the EAF steelmaking have been presented.** For instance, end-of-life tyres can be used instead of anthracite as carbon-based input. As an alternative, polymers created by waste plastic can be used as well as a re-carburising input. This is a win-win situation for all involved industrial sectors, but a certain attention to the legal and standardisation situation of the member state in which the EAF is operating is worthy. Residues from EAF steelmaking route such as dusts, slag and secondary metallurgy slag can be treated using innovative technologies. A new pyro-metallurgical process for recovery of zinc from dust was presented as a more efficient alternative to the Waelz process. A fast cooling process for the secondary metallurgical slag shows the possibility of valorising this residual stream for new demanding application and for having also positive economic returns. As final example, it has been mentioned the use of the EAF slag as filler material for polymeric matrices, giving then, to the new mix, new ferro-magnetic properties, possibly opening new applications and market segments. **The main benefits of a new treatments amount to a lower demand for primary resources and a reduced landfill volume as well as economic savings for steel plant operators However, certainty of legislation and rules and harmonization at EU level is required to speed up the development of the new value chains**.

Closure plenary section - Chairman: F. Praolini, K.Peters

An optimal management and higher valorisation of the ferrous, the valorisation, recovery and recycling of steel co-generated streams and improvement of the energy efficiency are key research topics for the steel production in general. The profound symbiosis between primary-integrated and EAF-electrical steel production routes in action today and that will be active in the future poses these three topics in a central position of the future strategy of the steel production.

EAF steel production, due to its characteristics, is in a good position to face the challenges and opportunities posed by both circularity and decarbonisation, as driven by the very ambitious EU policies and goals:

- **ferrous scrap** (and its availability and quality) could become a more and more strategic raw material, towards the full circularity in steel production.
  The KEY ASPECTS are:
  - ❑ increasing product recycling rates
  - ❑ scrap collection and management
  - ❑ improved use of low grades /post-consumer scrap
  - ❑ separation and elimination of undesired elements
  - ❑ "closing the loop" of scrap generation and utilization in UE
- **EAF residuals and byproducts,** when properly managed, meets chemical, physical and environmental requirements to be successfully valorized in many applications, saving natural resources and decoupling production growth from waste generation.
  The KEY ASPECTS:
  - ❑ further research for innovative uses and safe applications
  - ❑ cooperation with user sectors
  - ❑ certainty of legislation and rules - harmonization at EU level
  - ❑ enhancing the demand (green procurement and circular economy incentives)
  - ❑ solving undue conflict with chemical and waste legislation.
- **EAF indirect CO_2** will be significantly reduced by the greening of electric power in the coming years. Further improvement can be achieved on energy recovery, waste heat valorization and minimization of EAF direct emission associated to carbon charge.
  The KEY ASPECTS:
  - ❑ integration with renewable energy sources
  - ❑ competitive access to CO_2- free energy
  - ❑ thermal waste valorisation
  - ❑ energy efficiency
  - ❑ substitution of coal input with alternative material

An active cooperation between all stakeholders is key, including steel manufacturers, universities and research institutions, technology and industrial equipment providers, steel user sectors, public institutions at European and national levels.

ESTEP reminded to the audience its engagement in preparing the ground for the next round of possible EU funding calls focusing on steel production. Moreover, it recalled also that there is the intention of preparing a 'Clean Steel Roadmap for the EAF Steel production route', stressing steel companies in the audience to participate to this exercise and joining ESTEP in this effort.

This report was written by:

- Aurelio BRACONI
- Bernd KLEIMT
- Enrico MALFA
- Klaus PETERS
- Fabio PRAOLINI
- Alfredo SCHWEIGER
- Delphine SNAET

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