The european steel technology platform's strategic research agenda: a further step for the steel as backbone of EU resource and energy intense industry sustainability

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Steel has historically been central to modern economies, synonymous of growth and progress. Modern society would be impossible without steel: Europe 's reconciliation after World War II was built on unified coal and steel industries. Today the steel sector in Europe has an annual turnover of EUR 166 billion and it is responsible for 1.3% of the European Gross Domestic Product. Moreover, steel is the essential material for a circular economy, not only for its recyclability, but because it is a material that remains available to be reintroduced into a production process in order to give birth to products or materials (permanent material). Therefore, the sector has been recognized as one of three areas, along with space and defense, where the European Commission proposes specific policy measures.

In the last decades, the European steel industry has been under severe pressure, squeezed between brutal market conditions and the ever more stringent environmental regulation aiming at mitigating the climate change with the associated shift to a carbon-limited world. To face these challenges, apart from creating and maintaining a level playing field, the European steel industry has to rely on its highly skille d workforce and on its ability to deliver technological breakthroughs.

The paper summaries the vision of the European Steel Technology Platform's (ESTEP) Strategic Research Agenda (SRA) to address the challenges that the steel sector faces in terms of Rese arch & Development & innovation (R&D&I) in relation to sustainable steel production. Starting from the consideration that the sector finds itself very close to the physical limits of CO_2 emissions reduction from conventional steelmaking technologies, the EU steel industry has recently begun further analysis into how potentially novel solutions could achieve 'deep' decarbonisation, working on the following main pathways:

- Carbon Direct Avoidance (CDA), which substitutes carbon with hydrogen and/or via the use of electricity
- Smart Carbon Usage (SCU), which further optimises carbon -based Metallurgy and applies the circular use of waste carbon in synergy with other industrial sectors and the use of carbon storage methods to mitigate greenhouse gas emissions
- Enhancing the recycling of steel and its by-products, helping to improve resource efficiency and reinforcing the creation of a circular economy.

These targets are ambitious, and come at a cost, potentially of several billion euros. Thus, it is important to note that only joint initiatives with other industrial sectors, the EU institutions and the member states to support the necessarily time-consuming and expensive R&D, will foster the emergence of such breakthrough solutions. The 'Big Scale' initiative – i.e. the work on a joint initiative on low carbon steel – is a key component, which will be needed to accelerate carbon reduction over the entire steel value chain.

This should also contribute to the creation of the coveted circular economy in Europe, gi ven the huge potential of steel.

KEYWORDS: SUSTAINABILITY – CIRCULAR ECONOMY – CARBON DIRECT AVOIDANCE – SMART CARBON USAGE

INTRODUCTION: ESTEP OBJECTIVE AND MISSION

The European Steel Technology Platform (ESTEP [1]), funded in 2004, is a European 2020 ETP (European Technology Platform) that meets the criteria set by the European Commission. In fact ESTEP was set up in 2003 as an industry-led stakeholder forum and was recognized in 2004 as platform of steel having as one of the main objective the Ultra - Low CO2 Steelmaking - ULCOS [2]. In these 15 years, ESTEP has activated steel industry stakeholder and has been engaged in collaborative EU actions and projects on technology & innovation. In March 2018 the ESTEP, stating from original association without formal legal status, has been re-organized in a European not-for-profit association

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under the legal form of an international not-for-profit association established under the laws of Belgium.
The objectives of the ESTEP are:
• fostering European research, technology and innovation in the steel sector;
• working on common European research topics and projects and provides information services and guidance to its members;
• representing the common RTD interest of its members vis-à-vis third parties, notably the institutions of the European Union.
The ESTEP associates, that represent a significant proportion of the steel value chain (fig. 1), are organized to reinforce the ESTEP mission to engage in collaborative actions and projects on technology & innovation, which tackle EU challenges (notably on digitisation, the low-carbon future, circular economy, resource & energy efficiency, etc.) in order to create a sustainable European steel industry.
The vision of what Steel is to become in the medium and long term and of how it can get there is presented in the ESTEP's Strategic Research Agenda (SRA), an extensive document that is periodically revised and updated according to the most recent trends and results of the research in the field. The most recent version of the SRA, published in 2017 [3], covers four main pillars for steel sustainable growth:
• Planet dealing with innovative technologies, including breakthroughs, which help to meet environmental requirements, promote sustainable steel production and develop Life Cycle Thinking and Life Cycle Assess-ment;
• Profit ensuring profitmaking through innovation and new technologies within the production processes;
• Partners responding to the demands and needs of the society by working with the partners of the steel sector for proposing innovative steel products and steel solutions in the sectors of transport, construction and infrastructure, and energy;
• People attracting and securing human resources and skills in a dynamic way by optimizing the deployment of the human resources and becoming a worldwide reference for health and safety at work.

Fig. 1 – ESTEP stakeholders

THE CONTEXT OF STEEL INDUSTRY
The fundamental link between steel and development has been recently manifested in the enormous increase in production capacity and output in China and on a smaller scale in other emerging markets, matching ambitious economic development goals. However steel sector is characterized by cycles:
1. Europe's reconciliation after World War II was built on unified coal and steel industries;
2. the period ended with the first oil crisis in the middle of '70 and has been followed by a low growth of almost 3 decades until Chinese economy steeped in high growth phase at the beginning of this millennium. These more recent developments have however also led to a significant global over-capacity, aggravated by a slump in demand resulting from the fall-out of the 2008 financial crisis;

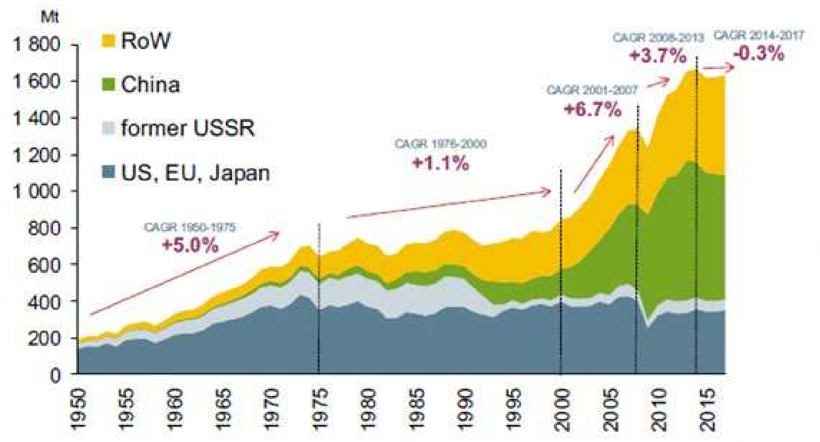

Fig. 2 – Crude steel production cycles

3. after 2012 China peaked and global steel demand is facing low growth period again;

4. today developed countries maintains low growth trend with about 200 kg of finished steel use per capita [5].

The moderate growth observed in 2016/17 has been confirmed in 2018. Hoping that the heightened level of trade tensions will abate, the Short Range Outlook of Word Steel suggests for 2018 a growth of 1.8% followed by a 0.7% in 2019 [5]. Steel demand is benefitting from the broad a favorable global economic momentum affecting both the developed and developing world at the same time.

In European Union (28) the steel sector has reached an annual turnover of EUR 166 billion, accounting for 10% of global output and is responsible for 1.3% of EU GDP. The 500 production sites in EU, in which 168,9 million tons has been produced in 2017, involve about 320,000 direct employer and about 2 millions of de-pendent jobs in value chain & service sectors spread all around EU [6].

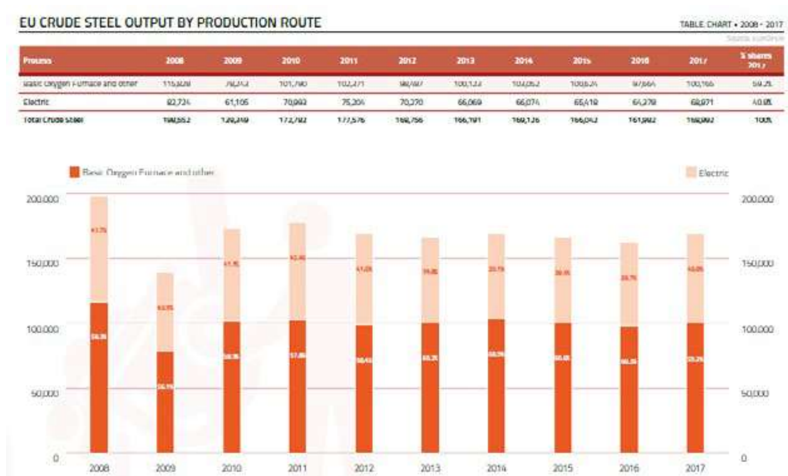

Fig. 3 – Eu crude steel output by production route

Therefore steel has been recognized as one of three sectors, along with space and defense, where the Juncker European Commission proposes specific policy measures [7-8]. At the same time Europe's steel industry has been under severe pressure, squeezed between brutal market conditions and the shift to a carbon-limited world. To conquer these challenges, apart from creating and maintaining a level playing field, the European steel industry has to rely on its highly skilled workforce and on its ability to deliver technological breakthroughs.

EU STEEL AND SUSTAINABILITY

Drivers, trends & costs

The iron and steel sector plays a key role in Europe's energy consumption ranking second, with 18%, belongs to the Resource & Energy Intensive Industries (R&EII). The high requirement of energy in the steel sector has an economic consequence on production cost (the energy amounts to 20-25% of operating costs). Such powerful drivers, has made possible to cut consumption of the steel sector by large amounts at the end of the 20th century, such as illustrated by EUROFER in its recent study "Steel and the circular economy" [9].

Regarding environmental policy, various instruments are being introduced or under review at EU or national level. Initiatives with a significant impact for the steel industry include:

- Integrated Pollution Prevention And Control (IPPC) permits;
- the Industrial Emissions Directives called (IED), which is the revision of this IPPC directive with the implementation of the BAT conclusions (Best Available Techniques) being the legal reference for permitting of installations;
- the new product and waste legislation (such as the Life Cycle Assessment approach and eco-design as well as PEF, the product environmental footprint);
- thematic strategies on natural resources, waste prevention and recycling;
- the EU legislation on chemicals ('REACH');
- the new Energy Efficiency Directive (EED);
- Circular Economy Directive.

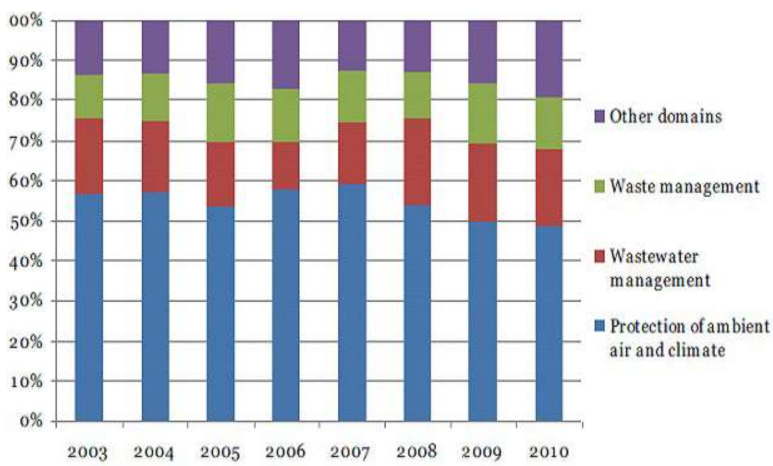

Fig. 4 – Environmental Protection Investments in steel in the previous decades [10]

This is the reason why there is continuous investment by steel industry for process optimization to conjugate the low OpEx with the reduction of environmental impact (fig. 4): irrespective of the source used, environmental protection investments made by the EU steel account for 5-9% of total investments in the steel industry (between € 3.6 billion and € 5.8 billion). However, environmental protection remain substantially a cost. In 2013, a study [10] estimate that cumulative costs of EU legislation on the European steel industry respect to production costs range from 7.65 to 14.18€/tonne. They represent about 3% of total costs for Electric Arc Furnaces (EAF) wire rods, 2% for Basic Oxygen Furnace (BOF) producing Hot Rolled Coils (HRCs) and Cold Rolled Coils (CRCs).

Steel as products

If we look at the "steel" as product, the SRA structures the future prospects for steels and steel industry by-product in the frame of Circular Economy, according to their final application: transport, construction & buildings, energy production, storage & transport. This is the clearest way to identify what progress is required to reach the targets of our society for the years to come. In addition a more transversal and abstract view is proposed to provide a guiding light for the analysis.

			BOF HRC	BOF CRC	EAF WR
ETS		Direct	-2.69	-2.69	-0.54
		Indirect	0.29	0.45	3.06
		Administrative	0.13	0.13	0.10
		Sub-Total	*-2.27*	*-2.12*	*2.62*
Energy		Transmission	1.58	2.40	3.48
		RES	2.09	3.18	4.65
		Sub-Total	*3.67*	*5.58*	*8.12*
Environment	Direct	Investment	1.35	1.35	1.13
		Financial	0.73	0.73	0.61
		Operational	4.05	4.05	3.39
		Administrative	*0.01*	*0.01*	*0.04*
		Sub-Total	*6.15*	*6.15*	*3.39*
Product	Administrative – REACH		0.10	0.10	0.05
		Sub-Total	*0.10*	*0.10*	*0.05*
		Total	***7.65***	***9.72***	***14.18***

Fig. 5 – Cumulative regulatory cost in 2012 [10]

First at all we have to underline that:

• Steel can be produced in thousands of different qualities and can be tailor-made for many final applications.

• Durability is an added value naturally afforded to steel-made products. Steel is a very long lasting material with constant performance during its use phase, allowing, for instance, bridge life spans of more than a hundred years. The majority of all the steel products ever made are still in use today.

• The steel elements of articles used in many applications can often be re-used, repaired or remanufactured at the end of their normal life, when properly designed, thus increasing their total life span.

• Steel elements within discarded products – such as domestic appliances, machineries, vehicles or constructions – can easily be collected, owing to their magnetic properties, and then recovered into several steel scrap qualities, each one with its own characteristics.

• Co-generated products from steelmaking processes, such as process-gases, iron oxides and ferrous slag, are successfully used in other sectors replacing natural resources.

• Steel is never consumed but continuously transformed through recycling processes that do not degrade its inherent properties. Thus, it perfectly fits with the concept of “permanent material”, which is at the basis of a circular economy and goes beyond the simplistic separation between “renewable” and “non-renewable resources.

Fig. 6 – Steel made in Europe: the backbone of sustainability

Moreover it is important to underline that the present energy system is built around steel. This has been true in the last century, it is true today and it will remain true in the future. The energy generation technologies based on renewables, due to the smaller scale with respect to traditional power plants, are several times more material intensive, including the steel among the required materials. Therefore, steel contributes to the reduction of "indirect CO_2" emission (fig. 7) both for its sector either, more in general, for EII.

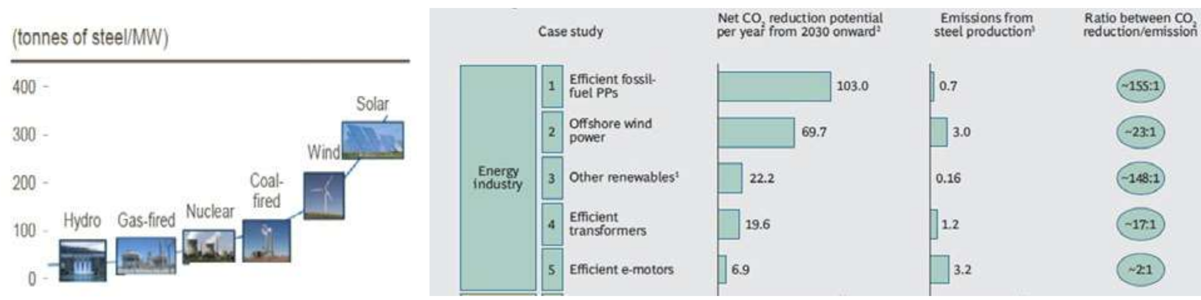

Fig. 7 – Innovative use of steel saves much CO2 as is caused by the production of the steel [11].

Similar, the automotive industry stimulates lightweight construction innovations. In this contest steel is a very efficient material regarding GHG emissions while taking into account the whole life cycle, i.e. the production phase, the use phase and the end of life (the effective recycling). It is essential for the steel industry to exploit its material expertise through material development and component design for use in mass production and, in cooperation with the transport and especially the automotive sector, to achieve further improvements or totally new solutions for vehicle concepts (fig. 8)

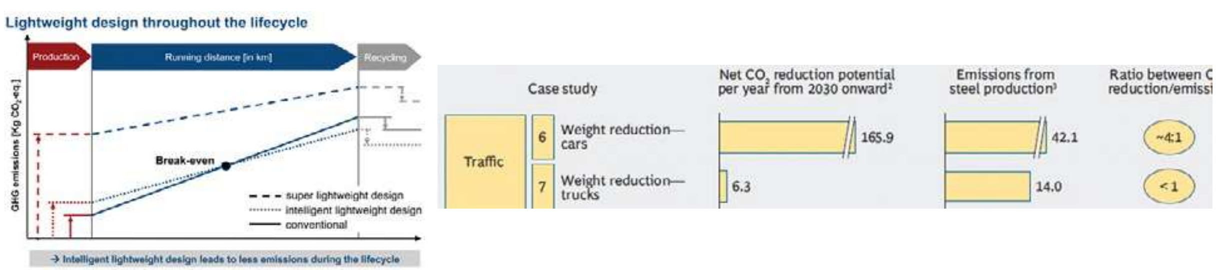

Fig. 8 –Innovative use of steel saves much CO2 as is caused by the production of the steel [4,11].

Steel in the circular economy

There has always been a strong incentive for society to collect steel scrap, due to its sustained economic value and the ease and low costs associated with its collection. Thus, a highly developed and mature steel recycling infrastructure – and associated business models and practices – has emerged over time (fig. 9 – upper). The European steel industry recycled about 100 million tonne of scrap (comprising both pre- and post- consumer) with a steel product-recycling rate of 90% from construction, 85% from automotive, 75% from packaging. Unfortunately, the definition of recycling contained in existing European Waste legislation (particularly the definition in the Waste Framework Directive [12]) is weak. It can easily be interpreted as "collection" or "preparation for recovery". It should be changed to make it more adherent with the aspirations of the Circular Economy taking into consideration the following aspects;

• recycling operations take place when materials reclaimed from waste are reintroduced in processes for incorporating them into new materials;

• recycling operations should be clearly differentiated from any recovery operation in order to better support the application of the waste hierarchy;

• any new definition should promote material-to-material recycling in which materials remain available to be reintroduced into a production process in order to give birth to products or materials (permanent material).

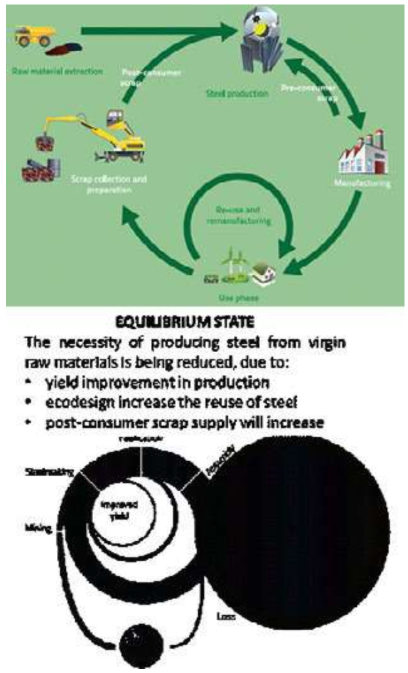

Fig. 9 – Steel a permeant material [9,15]

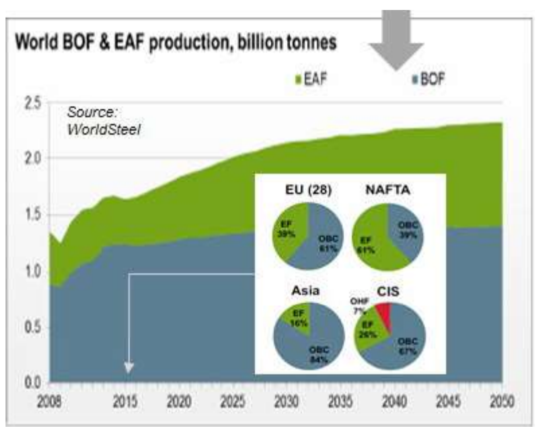

Fig. 10 – Word BOF & EAF production forecast (billion tonnes)

This can help to speed up the balance between integrated and scrap-based process routes (fig. 9 - lower). In fact at the moment as a consequence of the durability of steel products, there is not enough scrap available to completely satisfy society's increasing demand for steel [13-14]. Driven by a growing population and increased living standards, there will always be a need to introduce new steel from virgin production and iron ore is one of the most abundant resources in the earth crust. In this scenario NAFTA and EU are most exposed to the scrap availability and prices (fig. 10). In additional to scrap, the steel production has been working on circularity since its existence as yield improvement and energy savings: cascading use of resources, waste recycling, internal residues recovery and recycle are only some of the circular actions put into practice during the daily steel production. Process gases are used for electricity generation for industrial and domestic applications, replacing fossil fuels and natural gases. Ferrous slag is used in a range of applications (e.g. civil engineering like road construction, fertilizer and cement production etc.), saving millions of tons of natural resources annually (fig. 11). Further improvements can be foreseen if the rules on by-products will be clarified and consequently will facilitate industrial symbiosis and help create a level-playing field across the EU.

Fig. 11 – The by-product, a "wealth of glows" [16]

STEEL INDUSTRY AND CLIMATE CHANGE CHALLENGERS

Due to the effort done in the last 50 years, the sector finds itself very close to the physical limits of CO_2 emissions reduction from conventional steelmaking technologies (fig.12). Today, for every ton of steel pro-duced today, almost 24 GJ/ton are saved compared to 1960. That's enough energy to drive a car 17,380 km. CO_2 emissions from EU27 steel production fell by over 25% between 1990 and 2010, (from 298 Mt in 1990 to 223 Mt in 2010 – Fig.13). This was mainly due to:

• a partial shift from primary to secondary steelmaking (accompanied by a contraction of output);

• efficient gains and, to a lesser extent, to the decrease of specific CO2 emissions from electricity genera-tion.

In parallel the well known ULCOS (Ultra Low CO_2 Steelmaking [2]) programme was launched in 2004 to tackle the challenge of the maximum increase of 2°C by 2050 compared to pre-industrial levels. However, according to BCG/VDEh case studies [11] the ambitious objectives proposed in the Commission Low Carbon Roadmap for the ETS [13], to reduce of 43-48% by 2030 and 88-92% by 2050 the CO_2 emissions compared to 2005 levels (fig.14), is technically and economically unachievable for the steel industry unless alternative innovative steelmaking technologies are deployed at industrial scale.

To overcome this barrier, steel industry is working intensively on breakthrough solutions for further cuts in both carbon emissions and energy consumption to the mitigation of greenhouse gas emissions and for helping meet the objectives of the Paris Agreement [17]

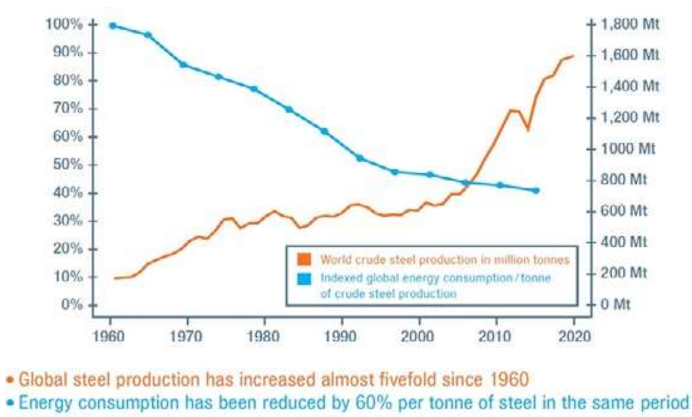

Fig. 12 – Specific energy consumption in the steel sector [source: World Steel]

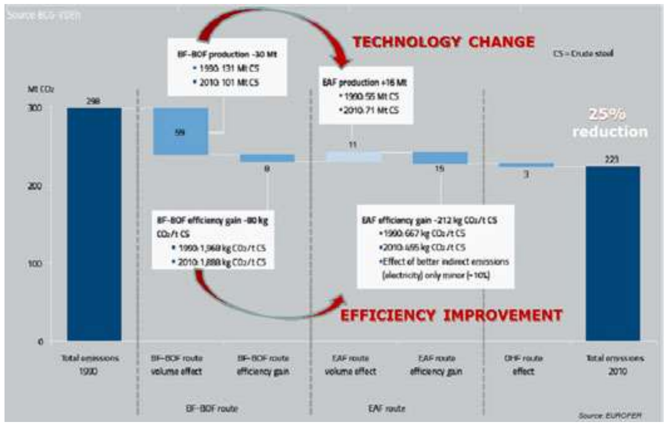

Fig. 13 – CO_2 reduction in steel sector [11]

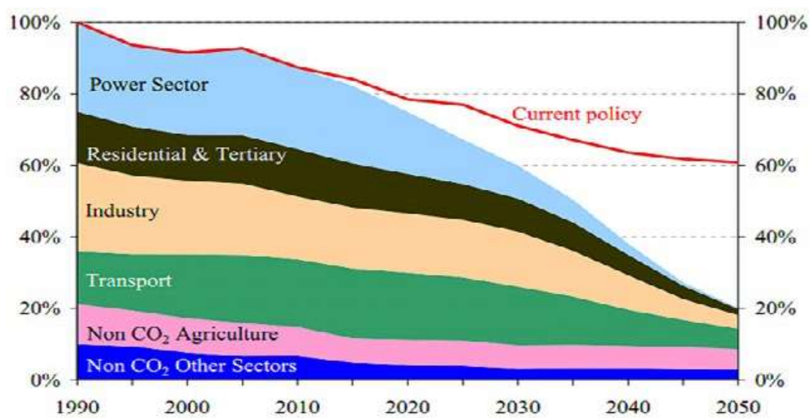

Fig. 14 – EU Emissions Trading System (EU Ets) targets

'Deep' decarbonisation

The EU steel industry has recently begun further analysis into how potentially novel solutions could achieve 'deep' decarbonisation, working on the following main pathways (Fig. 15).

As already pointed out if we look at the "steel" as product, the SRA structures the future prospects for steels and steel industry by-product in the frame of Circular Economy, according to their final application: transport, construction & buildings, energy production, storage & transport. This is the clearest way to identify what progress is required to reach the targets of our society for the years to come. The Masterplan target to extend the approach to more transversal one that may be useful as it can provide a guiding light for the intersectorial view. Steel industry has long tradition to recovery and valorization of by-products in solid (slag, dust, scale, sludge), liquid (water and oil) or gaseous streams to new feedstock but potentially also open to re use residues and by-products of other industrial sectors in the steel plant like biomass, plastics, rubber [19,20,21].

Smart Carbon Usage means making further use of existing, mainly coal-based steelmaking routes, using the CO_2 generated during the steel production process to produce chemical feedstock whilst employing carbon-lean or fossil free electricity. This pathway includes two promising groups: Process Integration (fur-ther development of existing processes) and Carbon Valorisation (also called Carbon Capture and Usage - CCU). Carbon Capture and Storage (CCS) will form an integral part of this pathway.

Carbon Direct Avoidance

Develops (new) processes that would produce steel mainly from virgin iron ore and/or suitable scrap gradu-ally maximising the use of carbon-lean or fossilfree electricity and/or hydrogen. The intention is the large-scale replacement of existing, mainly coalbased metallurgy, instead using direct reduction, plasma smelting reduction or electrolysis processes for iron ores, among others. This pathway includes two groups of promising technologies: mainly hydrogen-based metallurgy, and electricity-based metallurgy. The target is a 'deep' decarbonisation that has in any case to take into consideration that fossil carbon is not only an energy source for the steel industry but is also necessary as reducing agent in the liquid steel production pro-cesses. Alternative raw material and alternative process are available and/or are under investigation in order to minimize the CO_2 footprint (fig. 16).

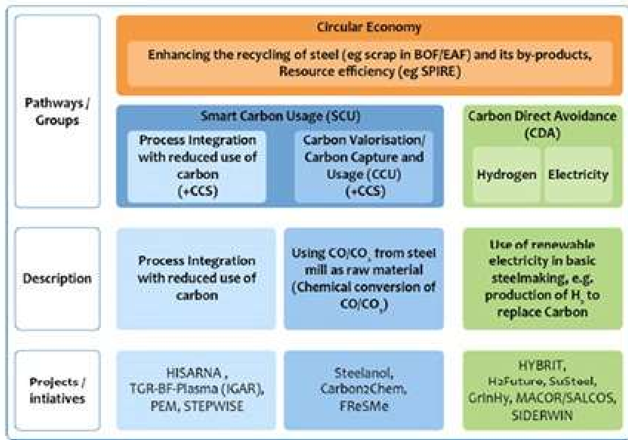

Fig. 15 – Technological pathways to CO2 reduction in steel [21,22]

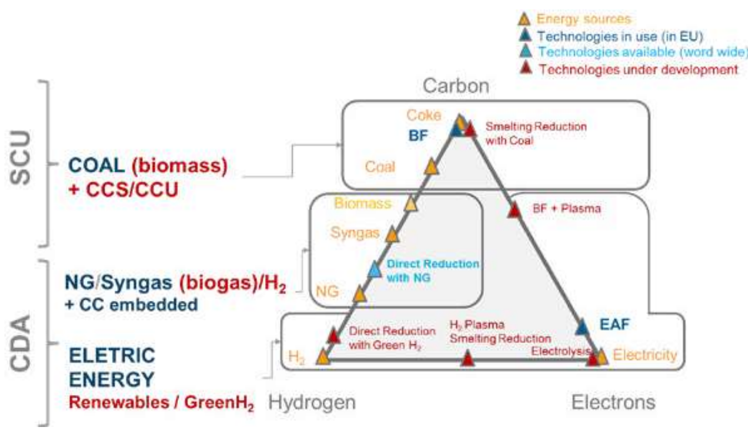

Fig. 16 – Alternative material and process for liquid steel production

The European steel industry is working on a range of techno-logies to bring about the most sustainable out-come by 2050. Some of the new technologies are under investigation in H2020 projects while other projects are in plane as private and /or nationally R&D investment (fig. 17). The ESTEP/EUROFER targets are ambi-tious [23]. By 2034, at least four projects are planned to have been upscaled to become industrial scale de-monstrators, of which at least two reach 80% CO_2 reduction from steelmaking, with or without Carbon Capture and Sto-rage. By 2050, a new low-carbon steel value-chain should be in place. The industry endeavours to have shifted from a fossil-energy-based linear industry to a low-carbon energy-based sector integrally part of the circular economy, and emitting at least 80% less CO_2 compared to 1990 levels. Europe could be-come a leading provider of low-carbon products, services and technologies in steelmaking world-wide.

The European steel industry estimates that bringing ongoing projects up to industrial scale will require an additional finan-cing of up to 11 billion euros in the years 2021-2034. The 2021-2027 timeframe will be a crucial preparatory phase. The-re are plans to initiate some of the industrial scale projects in the first years of Horizon Europe, while others will start later, following different technological pathways and timelines. Other sources of financing, including the EU ETS Innovation Fund and Important Projects of Common European Interest (IPCEIs), will support the scaling up of projects at industrial scale, both in the 2021-2027 and 2028-2034 periods.

However, low-carbon technologies are not only a challenge for the steel industry. It requires fundamental transformation of energy management to maintain the competiveness of R&EII industry (i.e.EU steel electricity consumption today is ~75 TWh. If 100% will be based on H_2/electricity/CCUS the consumption will grow to ~ 400-500 TWh, about 18% of current EU total consumption). In particular the Carbon Direct Avoidance route requires a clear EU plane to have available renewable energy and green-H_2 for all the potential users (energy-intensive industries, mobility, etc.). This should allow having a realistic and positive framework for projects up to industrial scale demonstrators and market roll-out ensuring that neither new technologies nor existing installations face competitive disadvantages within the internal market or vis-à-vis global competitors in the transition to a low-carbon industry. Thus, it is important to note that only joint initiatives with other industrial sectors, the EU institutions and the member states to support the necessarily time-consuming and expensive R&D, will foster the emergence of such breakthrough solutions. In particular the CDA route (right side of fig. 15) that is based on gradual substitution of carbon with alternative energy sources as alternative to CO_2 usage (CCU) or disposal (CCS) concepts requires a fundamental transformation of energy sector in EU (generation, supply, infrastructure, …) and a cross-sectoral approach between R&EII and energy suppliers. This is fundamental both for conventional source like NG and biogas either for renewable energy & green H_2 [21].

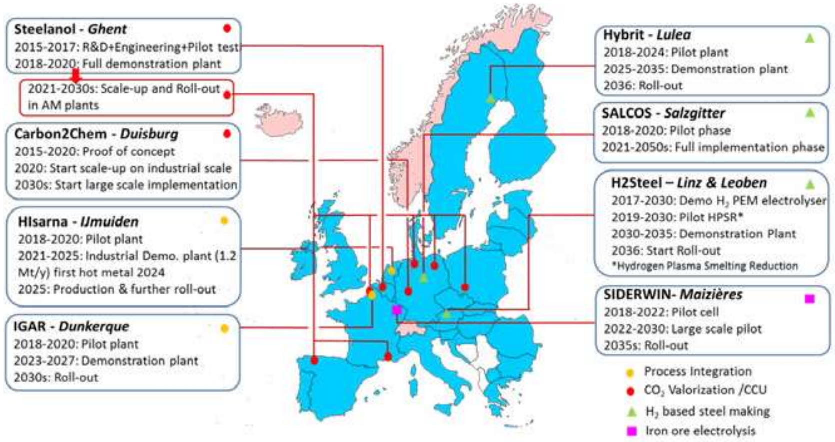

Fig. 17 – Mapping of key innovative carbon neutral projects of the EU steel industry [source EUROFER]

Figure 18 show the example for Direct Reduction Process (DRP) that in principle allows following EU CO_2 reduction targets realizing a stepwise transformation process of integrated iron and steel works towards DRP- and electrical energy-based steelmaking processes. As a first step, an additional gas-based DRP has to be realized to produced high carbon DRI (HC-DRI) to be utilized in existing Blast Furnaces (BFs) to enhance productivity and to reduce coke as well as PCI in parallel. This step already reduces the carbon footprint of steel production by around 10%, as natural gas used for reduction has a certain amount of hydrogen content. With electrolysis on an industrial scale hydrogen can further replace natural gas and so carbon carriers partly. In case of operating electrolyzers with power from renewable resources only, the overall CO_2 emissions can be reduced up to 18%. The next step will be the incorporation of a melt shop to produce steel via EAF-based route. Further steps in this transformation process are principally based on the same approach as the steps before, leading to the complete change of steelmaking from the BF/BOF technology to the DRP. With the final configuration (H_2-green based reduction/EAF route) the resulting reduction in CO_2 emissions will be reach the 2050 EU target.

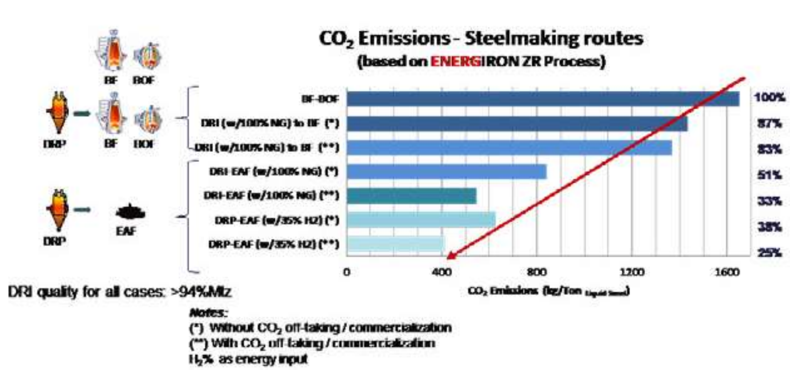

Fig. 18 – Reduction of Carbon footprint based on DRP [24]

CONCLUSIONS

Investment in the steel industry is very capital intensive and requires a long planning horizon. The European Steel Technology Platform's (ESTEP) through its Strategic Research Agenda (SRA) addresses the challenges that the steel sector faces in terms of R&D&I in relation to sustainable steel production: the most significant of our time is climate change. In this frame the European steel industry is fully committed to the mitigation of greenhouse gas emissions, to helping meet the objectives of the Paris Agreement and the EU's target of reducing domestic CO_2 emissions by 80% to 95% by 2050 compared to 1990 levels. The required breakthrough innovation investments can only be made if the EU's Long-Term Climate Change Policy Strategy sets out the ambition to apply:

1. The right Research & Innovation framework to develop key low-carbon technologies;
2. The use of low-carbon energy at globally competitive prices for energy intensive industries, given that a huge amount of additional carbon-lean energy - and the associated infrastructure - will be needed for the transition of the industry;
3. Effective policy measures that keep European low-carbon industrial production competitive on both internal and global markets.

Synergy effects between projects, technologies and sectors will create the dynamics needed to drive low-carbon industrial production. These synergies will help build up greater skills, jobs and open up new markets, including for low-carbon steel, hydrogen, alternative fuels and feedstocks for the chemical industry, enhancing the circular economy.

Moreover, to support successful investment management in the steel industry it is key that effective and reliable measures are in place that allow for the planning of long-term investments related to innovation and carbon costs, including after 2030. A policy that neutralises the costs of these challenges versus global competitors needs to be in place as soon as possible to allow for these investments in the EU.

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