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Special Issue on 'The role of Hydrogen in the transition to a sustainable steelmaking process' edited by Ismael Matino and Valentina Colla

EDITORIAL

The role of hydrogen for a sustainable steelmaking process

Climate change is one of the main issues of the current society, which is increasingly becoming aware that urgent actions are needed to face it.

In this context, European Union (EU) launched the European Green Deal and REPowerEU programs for promoting decarbonisation, production and usage of sustainable energy and for becoming the world reference for climate change fight. Several activities are promoted in the different productive sectors as well as in the society, and significant contributions are expected by energy intensive industries.

Steelmaking industry belongs to this category and, despite of continuous efforts spent to improve its environmental sustainability, it is still responsible of about 22% of industrial EU CO_2 emissions. Therefore, the steel sector is promoting research and is committed to develop and deploy novel technologies for its decarbonisation.

Steelmaking decarbonisation can provide significant contributions to reach the Green Deal ambitions of making Europe fossil-independent, climate-neutral and leader for C-lean products.

In addition, the exploitation of new energy sources is now more necessary than ever considering the current geopolitical situation. In this background, hydrogen can have a fundamental role for sustainable steelmaking, as both existing and innovative routes can take advantage from its application. H_2-based steelmaking can become a fundamental route in the future, and the replacement of fossil carbon energy can be achieved, among others, through H_2-based heating. Furthermore, hydrogen can be important to allow valorisation of CO_2 rich gases coming from the steelmaking production. However, suitable low-carbon hydrogen production routes, infrastructures, markets and norms are needed to enable this transition and to maximise the benefits deriving from a wide and multipurpose usage of hydrogen in steelmaking sector.

The European Steel Technology Platform (ESTEP) is highly involved in steelmaking decarbonisation and promotes activities to support the transition towardsC-lean steel production by hydrogen application. In addition, knowledge dissemination, experts brainstorming and discussion for addressing existing issues and gaps related to C-lean steelmaking and hydrogen exploitation are considered fundamental by ESTEP, who organised in autumn 2022 the second edition of a thematic conference to discuss the role of hydrogen for a sustainable steelmaking process. The 3 days conference, entitled "*H_2 for Green Steel*" was hosted by Air Liquide in the Innovation Campus Paris Air Liquide, close to Versailles in France. The first day was dedicated to a visit to the Air Liquide Normandie hydrogen production plant, while in the other two days a total of 30 presentations, opening and keynote lectures were provided by expert researchers in the field coming both from steelmaking, hydrogen, refractories industries as well as from plant and technology providers, and academia. Each session included interactive discussions between lecturers and audience favouring the brainstorming. In addition, the conference was opened by the appreciated and interesting lectures of ESTEP Secretary and European Commission Clean Planet Partnerships Manager.

The present special issue collects a selection of the themes discussed during the above-mentioned Conference, which were provided on a voluntary basis by the authors and passed a further peer-reviewing stage. Therefore, the focus is on hydrogen usage, related challenges, and gaps to be filled for contributing to the decarbonisation of the steelmaking process.

Noteworthy a deep investigation of available press and literature articles on hydrogen usage in steelmaking is provided in the paper entitled "*Net-zero transition in the steel sector: beyond the simple emphasis on hydrogen, did we miss anything*?". Its main aim is to highlight the current state of the art and the emphasis on the hydrogen topic and to analyse what are the important issues still rarely discussed (e.g. iron ores for H_2-DR, carbon to be fed, shaft design, refractories in the new reactors, etc.) that are however fundamental to be addressed to allow the Hydrogen application in the steel sector and the C-lean steelmaking transition in a reasonable time horizon and without having to deal with overlooked problems. In addition, extra-European countries roadmaps are introduced showing similarities and differences with respect to EU, and highlighting how different parallel process routes will be developed in the upcoming years.

An interesting analysis is presented in "*Pathways Towards Full Use of Hydrogen as Reductant and Fuel,*" where the author provides an overview of short-, medium- and long-term actions that should be followed to achieve the C-lean and green steelmaking transition. The hydrogen role and the impact of geographical dislocations are included in the discussion. Transformation of blast furnaces to greener plants is considered a good intermediate step to achieve sustainability improvement in the short term; the analysed options to achieve this goal include increase of blast temperature, higher usage of scrap and DRI/HBI ratios, use of alternative fuels and CO_2 capture. Depending on the geographical location hydrogen usage as fuel is considered easily applicable in the short term. Then direct reduced iron production with partial use of hydrogen as a reductant can increase its importance in the medium period especially if coupled with carbon capture technologies. Only through this stepwise approach and clearly defined milestones, the finishing line can be achieved consisting in having the norm of a full use of hydrogen as a reductant, renewable fuels and electricity as sources of energy, and green steel as product.

As also mentioned in the previous paper, hydrogen exploitation as fuel is considered worthy of note application for achieving CO_2 emission decrease; obviously 100% hydrogen cannot be used in the short term and the use of hydrogen/natural gas blend is foreseen in the short period. This is the topic addressed in "*Flexible hydrogen heating technologies, with low environmental impact,*" where a "hydrogen ready" burner flameless technology is presented covering all the natural gas/hydrogen blends up to 100% H_2 without hardware modification. Such technology can be applied in a wide range of downstream processes. Carried out tests demonstrate that the burners can control NO_x formation in all the possible fuel blends. First industrial applications are presented, and open points are highlighted (e.g. concerning the effect of new combustion atmospheres on the steel product) to suggest the need of best practices for supporting the application of these burners in case of significant availability of low-CO_2 hydrogen.

An alternative hydrogen use in steelmaking industries consists in enriching carbon-rich process off-gases (e.g. process off-gases from integrated steelmaking route) to allow their chemical valorisation for the synthesis of methane and methanol. This application, which can be significant especially in the transition period towards C-lean processes, is treated in "*Hydrogen intensified synthesis processes to valorise process off-gases in integrated steelworks*". The authors provide an overview of all the activities carried out during an EU-funded project related to the valorisation of process off-gases in integrated steelworks. After presenting preliminary simulations and laboratory tests activities, three cutting-edge reactors and an advanced dispatch-controller are presented together with the results of successfully conducted tests: almost full CO_x conversion was obtained under flexible operations through smooth control strategy. Meaningful scenarios are discussed in a techno-economic analysis; it was demonstrated that significant environmental and economic benefits can be achieved for steelworks through the investigated solutions, but higher availability of green electricity and lower price of renewable energy sources are needed to allow a competitive production of hydrogen that is fundamental for the proposed chemical valorisation of process off-gases.

All the papers in this special issue, the analysed literature and current background highlight that, although hydrogen is considered a means and an enabler for achieving steelmaking decarbonisation, the availability and cost-effectiveness of low-CO_2 hydrogen is still limited. For this reason, alternative hydrogen production routes can help especially in the short-term period as described in "*Hydrogen production from coke oven gas using pressure swing adsorption process – a mathematical modeling approach*". The work describes the possibility to produce high purity hydrogen from coke oven gas through a pressure swing adsorption (PSA) technology by allowing conducting integrated steelmaking route in a more sustainable way in the first phase of transition towards C-lean processes. A mathematical model is presented and exploited for analysing and optimising the process: it was proved that an optimised 14-step multi-bed PSA cycle is suitable to achieve a recovery of about 75% of hydrogen from coke oven gas with a purity higher than 99.999%.

Finally, an auxiliary but highly important aspect related to the hydrogen use is analysed in "*Application of laboratory and on field techniques to determine the risk of hydrogen embrittlement in gaseous hydrogen and relative mixtures transport and storage*". A safety risk is indeed intrinsic in the usage of hydrogen due its reactiveness and to the susceptibility of steels to embrittlement phenomena. Therefore, the usage of suitable materials and their check through the preliminary and continuous evaluation of their behaviour when exposed to rich-hydrogen atmosphere is fundamental to avoid catastrophic failures. The paper addresses this aspect by analysing methods for determining hydrogen thresholds for failure and for innovatively checking hydrogen embrittlement in real-time; results of related tests campaigns are shown and discussed proving the effectiveness of proposed methods.

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