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Use of biomass in integrated steelmaking – Status quo, future needs and comparison to other low-CO_2 steel production technologies

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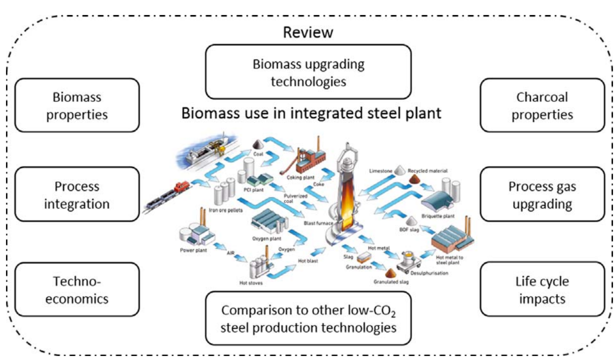
HIGHLIGHTS

- Biomass upgrading processes to produce fuels for iron and steelmaking are reviewed.
- Insights and recommendations for biomass-based reducing agent research are suggested.
- Process integration opportunities to increase economics and efficiency are proposed.
- Biomass use in steelmaking is compared to other low-CO_2 steel production technologies.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper provides a fundamental and critical review of biomass application as a reducing agent and fuel in integrated steelmaking. The basis for the review is derived from the current process and product quality requirements that also biomass-derived fuels should fulfill. The availability and characteristics of different sources of biomass are discussed and suitable pretreatment technologies for their upgrading are evaluated. The existing literature concerning biomass application in bio-coke making, blast furnace injection, iron ore sintering and production of carbon composite agglomerates is reviewed and research gaps filled by providing insights and recommendations to the unresolved challenges. Several possibilities to integrate the production of biomass-based reducing agents with existing industrial infrastructures to lower the cost and increase the total efficiency

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are given. A comparison of technical challenges and CO_2 emission reduction potential between biomass-based steelmaking and other emerging technologies to produce low-CO_2 steel is made.

Nomenclature

Abbreviations

AFC	ash free coal
BF	blast furnace
Bio-SNG	synthetic natural gas produced from biomass
BOF	basic oxygen furnace
CCS	carbon capture and storage
CRI	coke reactivity index
CSR	coke strength after reaction
DTF	drop tube furnace
DRI	direct reduced iron
EAF	electric arc furnace
EU	European Union
EU ETS	European Emission Trading Scheme
GHG	greenhouse gas
HM	hot metal
IPCC	intergovernmental panel on climate change
LCA	life cycle assessment
LPG	liquefied petroleum gas
NG	natural gas
PC	pulverized coal
PCI	pulverized coal injection
PSA	pressure swing adsorption
RAFT	raceway adiabatic flame temperature
RHF	rotary hearth furnace
SR	smelting reduction
SRP	self-reducing pellet
TGA	thermogravimetric analysis
VM	volatile matter

1. Introduction

Global climate change has initiated huge attempts to reduce carbon dioxide emissions. The European Union (EU) has been a forerunner in combating climate change through policy development towards a low-carbon economy [1–3]. The ambitious goal is to gradually reduce greenhouse gas emissions to 80% below 1990 levels by 2050. The milestones are 40% emission cuts by 2030 and 60% by 2040 [3].

The iron and steel industry is one of the biggest industrial carbon dioxide emitters accounting for 4–7% of the global emissions [4] and a similar range in Europe [5]. A study by Pardo and Moya [5] showed that the attainable CO_2 reduction, while still maintaining the competitiveness of the European steel sector, is in the range of 14–21% by the year 2030 compared to 2010. This requires both incremental development of current technologies and incorporating new, innovative technologies. The adoption of these innovative technologies is heavily dependent on the future prices of fuels, energy and other resources as well as carbon pricing. According to another recent study of steel industry decarbonization by Boston Consulting Group and VDEh [6], there is no feasible option to economically decrease the CO_2 emissions by 2050 to the extent of European Commission targets. In the economic scenario, the steel sector's specific CO_2 emissions would decrease by about 15% in 2050 compared to 2010. The maximum specific CO_2 emission reduction potential achievable by the European steel industry according to BCG/VDEh study is around 57% in 2050 compared to the 2010 level. This would require the retrofitting of all the blast furnaces (BFs) with top-gas recycling and carbon capture and storage (CCS) [7].

The use of biomass in iron and steelmaking has been acknowledged as being one possible solution to decrease fossil-based CO_2 emissions [8]. The motivation for the fuel switch from fossil to renewable fuels is that the net increase of direct CO_2 emissions is avoided since the growing plants will capture the emitted CO_2 from the atmosphere during their growth [9]. However, the question of direct and indirect land use change and its impact on the carbon neutrality of biofuels has been raised in recent years [10]. The biomass and soil carbon stocks are reduced when biomass is used for biofuel production [11]. The recent biomass availability evaluations suggest that global biomass potential is expected to increase in the following decades. The global techno-economic biomass potential in 2035 is projected to be in a range of 134–166 EJ, which is 2.4–3.0 times higher than the use of biomass as an energy resource in energy production in 2012 [12]. According to the review conducted by Slade et al. [13], the biomass potential ranges from under 100 EJ/year to over 1100 EJ/year in 2050. Estimations of market bioenergy potential suggest that 100–200 EJ/year should be achievable [14,15]. On the European scale, energy crop potential varies between 4.3 and 6.0 EJ/year in 2030 and 3.0–56.0 EJ/year in 2050. Residue potential from agriculture ranges from 0.9 to 3.1 EJ/year in 2030 and from 0.6 to 5.0 in 2050. Forest biomass potential in 2050 ranges from 0.8 to 10.6 EJ/year [16].

Despite the possibility to lower fossil CO_2 emissions with biomass in steel industry and increasing biomass availability potential in the coming decades, biomass has not been considered alongside other drastic measures to mitigate CO_2 emissions in iron and steelmaking. The main reason might be that there is a lack of knowledge concerning the full potential of biomass-based fuels in metallurgical applications including reachable CO_2 emission reduction. There are review papers available in the scientific literature, in which the biomass-based fuel use in the metallurgical industry has been investigated [8,17–19]. The previous review papers have dealt with wide ranges of steel production routes from economic and environmental perspectives to highlights in technical issues. This review will, in contrast, concentrate on biomass application in the most commonly used integrated steel production route. The process requirements will be evaluated for specified units with a more structured manner. The process requirements define the limitations in the physical, chemical and metallurgical properties of reducing agents, which biomass-based reducing agents should meet. This review will highlight the developments in biomass upgrading to meet the aforementioned requirements and investigates the current state-of-the-art literature of biomass-based reducing agent research. Critical issues that have been solved and those challenges that remain unsolved are discussed. Special emphasis is placed also on the economic and environmental feasibility of biomass use and comparison to other drastic CO_2 emission reduction technologies. Insights for future research are given for technology and supply chain development.

2. Iron and steelmaking

2.1. Steel production routes

Iron and steelmaking technologies can be classified into four main routes including blast furnace/basic oxygen furnace (BF-BOF route), melting of scrap in electric arc furnace (mini mill route), direct reduction iron/electric arc furnace (DRI-EAF route), and smelting reduction/basic oxygen furnace (SR-BOF route). The integrated steel production (BF-BOF route) is considered the most important route for steel production and it represents about 70% of world steel production.

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