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Biomass applications in iron and steel industry: An overview of challenges and opportunities

Elsayed Mousa [a,b,*], Chuan Wang [a], Johan Riesbeck [a], Mikael Larsson [a]

[a] Process Integration Department, Swerea MEFOS, SE-971 25 Luleå, Sweden
[b] Central Metallurgical Research and Development Institute (CMRDI), B.O Box 87, Helwan, Egypt

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ABSTRACT

The iron and steel industry accounts for about 20% of the annual industrial energy utilization. The intensive fossil fuel consumption in steel industry is associated with CO_2 emission. In the absence of economically feasible and efficient methods for capture and storage of enormous quantities of CO_2 emissions from steel industry, the use of biomass products as a source of energy and reducing agents provides a promising alternative solution for green steel production. However, the biomass application in iron and steel industry is still limited and it suffers strong competition from fossil fuels. The challenges of biomass usage in steel industry are included technical and economic aspects which required synergy between steelmaking and bioenergy sectors. Although intensive work has been carried out separately, there is a lack of link between these two vital sectors. The present article provides a comprehensive review of recent research progresses which have been conducted on biomass upgrading and analysing the opportunities and obstacles for biomass implementation in iron and steel industry. In the first part, an overview on the energy consumption and CO_2 emissions in different iron and steelmaking routes is clarified. Moreover, the potential approaches of biomass conversion processes and upgrading technologies are reviewed. In the second part, an attention has been paid to the utilization of torrefied/pyrolyzed biomass in the energy-intensive ironmaking processes. Biomass addition to coal blend during cokemaking and its influence on the product coke quality is discussed. The partial and complete substitution of coke breeze with biochar in sintering process and its influence on the product sinter quality is explained. The impact of charcoal top charging or injection into blast furnace has been elaborated. Benefits and limitations of biomass application in each process are thoroughly discussed. In the third part, an economic analysis of biomass implementation for low-carbon steel is addressed.

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* Corresponding author at: Process Integration Department, Swerea MEFOS, SE-971 25 Luleå, Sweden.
E-mail address: elsayed.mousa@swerea.se (E. Mousa).
URL: http://www.swerea.se/en/prisma/contact/meet-prisma (E. Mousa).

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1. Introduction

Iron and steel making is one of the most important industrial sectors which have a great impact on the global growth and economy. The steel production is sharply increased in the recent years to reach more than 1662 million tonnes in 2014, up by 1.2% compared to 2013 [1]. By 2050, steel usage is expected to increase to become 1.5 times higher than present levels in order to meet the needs of a growing population. On the other hand steel manufacturing is one of the largest energy- and carbon- consuming sectors. The global energy consumption in steelmaking is estimated to be about 20% of the annual industrial energy requirements. The fossil fuels represent the main source of heat and reducing agents in steelmaking and it is major contributor to global anthropogenic CO_2 emissions. According to the International Energy Agency, the iron and steel industry accounts for approximately 6.7% of total world CO_2 emissions [1,2]. The CO_2 emission from iron and steelmaking was 2.3 billion tons in 2007 while it is expected to reach 3.0 billion tons in 2050 [3]. Nowadays, the reduction of specific energy consumption and gas emissions are coming on the top priorities of iron and steelmaking due to the dynamic growth of energy prices as well as the commitment of governments to decrease CO_2 emissions according to Kyoto protocol [4]. The ironmaking process is the highest CO_2 emission part in steel production sector due to the intensive utilization of fossil fuels for heating, melting and reduction of iron ores. The most common technology for ironmaking is blast furnace which produces about 70% of total world steel production. Recently, the ironmaking processes have undergone tremendous modifications and improvements to reduce the energy consumption and CO_2 emissions, however further reduction is still required to secure the future sustainability of this vital industry. The modifications and improvements in energy consumption have been offset by increasing the total production and consequently the CO_2 emission continued to rise dramatically. Projections of future energy usage and CO_2 emission show that these trends will be continued unless decisive action and innovative strategies are considered. Therefore, reducing emissions from iron and steel industry requires sustainable and unlimited efforts for development and deployment of new trends and innovations.

Although steel industry is energy and carbon intensive, it is important to mention that it represents the core of green economy. The sectors and technologies which drive the green economy such as wind energy, low-carbon transport, clean energy vehicles, fuel efficient infrastructure and recycling facilities are all dependent on steel products. According to EU ambition, an 80% cut of fossil CO_2 emission should be achieved by 2050. Therefore, an increasing attention has been recently paid on using renewable biomass as a source of heating and reducing source instead of fossil fuels to mitigate the CO_2 emission in iron and steel industry. From both economic and technical point of view, the partial substitution of fossil fuels coal and coke with renewable biomass products in ironmaking processes represents one of few options which could be introduced in short and middle terms [5]. The application of biomass, especially the thermally treated products, is able to provide many advantages for steel industry. The biomass has unique properties represented in: renewability, carbon-neutrality, low sulphur content, low ash, high reactivity, high specific surface area and stable pore structure. On the other hand, the biomass application in iron and steel industry is still limited and it suffers strong competition from fossil fuels. The challenges of biomass usage in steel industry include both technical and economic aspects. The synergies between biomass-based sectors, biomass upgrading sectors and steelmaking sectors are of high importance to enhance the overall performance, efficiency and sustainability of these vital industries. This paper explores in detail the main challenges faced by steel industry and the potential of biomass to mitigate these challenges. Analysis of biomass resources and the recent activities which have been conduct on biomass upgrading are addressed. The opportunities and barriers of biomass implementations in the energy-intensive processes (e.g. cokemaking, sintering and blast furnace) in steelmaking are thoroughly discussed.

1.1. Iron and steelmaking technologies

Steelmaking process can generally be classified into four main different routes including blast furnace/basic oxygen furnace (BF-BOF), direct reduction/electric arc furnace (DRI-EAF), smelting reduction/basic oxygen furnace (SR-BOF) and melting of scarp in electric arc furnace (EAF). Fig. 1 shows the various steel production routes from the raw materials to the crude steel production [6]. The BF-BOF route is the most important way for steel production using mostly coke and coal as energy and reducing agents. The BF-BOF route represents about 70% of the world steel production [6,7]. The recycling and melting of steel scrap in EAF represents the second important route for steel production after BF-BOF and it accounts for 25% of world steel production. The DRI-EAF route uses mainly natural gas as a source of energy and reducing agent and produces approximately 5% of the world steel. The SR-BOF route is based on the combustion of coal for the reduction of iron ores without agglomeration and produces only 0.4% of the world steel production.

1.2. Energy consumption and CO_2 emissions in steel industry

In the last 20 years, technology has become one of the main drivers of economic and social development. As a result, the global consumption of electricity and primary energy in the end-use sectors has been sharply increased as can be seen in Table 1 [8]. A projection on 2020 indicates a further increasing in the energy consumption and CO_2 emission. The CO_2 emission has been increased from 21 Gt (Gigatons) in 1993 to 30 Gt in 2011 with an expectation to reach 42 Gt in 2020. The global energy consumption by end-use sectors reached about 9624 toe (tonne of oil equivalent) in 2010 as can be seen in Fig. 2a [9]. The industrial sector consumes more than 52% as given in Fig. 2b. The fossil fuels (coal, oil and natural gas) covers 79.5% from the total primary energy usage in all sectors as shown in Fig. 2c. In 2012, the global CO_2 emissions from all sector was reached 31.7 Mt as given in Fig. 2d [10]. About 42% of the total CO_2 emission comes from the production of electricity and heat. In the case of industrial sectors; the iron and steelmaking consumes about 20% of total energy usage (474 exajoules) in industrial sectors as shown in Fig. 3a [11]. The total CO_2 emission from industrial sectors is about 9.0 Gt from which 2.0–2.3 Gt is emitted from iron and steelmaking. This accounts 26–30% of the total annual emissions as shown in Fig. 3b [12]. The fossil fuels (coal, oil and natural gas) cover more than 70%