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CO_2 ABATEMENT IN THE IRON AND STEEL INDUSTRY - THE CASE FOR CARBON CAPTURE AND STORAGE (CCS)

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The steel industry is amongst the most energy-intensive industries also consuming large amounts of coal and emitting significant volumes of carbon dioxide (CO_2). Studies indicate that steelmaking accounts for 6 - 7 % of world anthropogenic CO_2 emissions, and 27 % of the total emissions of the world's manufacturing sector. Steel manufacturers have responded to sustainable resource use and development adopting several measures attaining a reduction in energy consumption of 60 % in the last 50 years. The paper discusses Carbon Capture and Storage (CCS) as a CO_2 mitigation option, after the 2015 Paris Climate Conference (COP 21) and in relation to the European Regulation for CO_2 measurement, reporting and verification.

Keywords: iron and steel, production, energy intensity, CO_2 emissions, CO_2 mitigation

INTRODUCTION

The resolutions adopted at the 2015 Paris Climate Change Conference in December 2015, have been heralded as a history-making agreement, after the warmest year ever recorded in human history, with the concentration of carbon dioxide (CO_2) exceeding the symbolic threshold of 400 parts per million (ppm), in the earth's atmosphere [1]. The agreement highlights the intent of all Parties to limit global temperature rise to 1,5 °C instead of 2 °C, [2] and to update national targets every five years. With the Kyoto Protocol entering into force in 2005, a set of methodologies for the preparation of greenhouse gas (GHG) inventories were introduced, according to Article 5 which commits Annex I Parties to apply a national system estimating greenhouse gases (GHG) emissions by source and removal [3]. Iron and steel production of leads to emissions of CO_2, methane (CH_4), and nitrous oxide (N_2O), all considered GHG. CH_4 is not considered here, and N_2O emissions are negligible [4]. In 2015, the iron and steel industry was the second largest industrial user of energy, consuming 25,8 EJ and the largest industrial source of direct CO_2 emissions (2,87 Mt CO_2 / t_{cs}), compared to 23,25 EJ and 2,3 Mt CO_2 / t_{cs}, in 2007 respectively. These figures indicate that management of CO_2 emissions is a significant challenge for the sector, according to Art. 14 of European Directive 2003/87/EC on measuring and reporting carbon footprints, as well as the EU's climate and energy framework, adopted by EU leaders in October 2014. This entails a minimum 40 % reduction in GHG emissions (vs 1990 levels), followed by, at least, a 27 % share for renewable energy and, at least, a 27 % energy efficiency improvement, by 2030.

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RESEARCH METHODOLOGY

Even though a limited number of processes are applied in iron and steel making worldwide, a complex industrial structure exists, leading to differences in energy intensities and CO_2 emissions on a plant and country level due to variations in the quality of the resources used, the cost of energy, cost-effectiveness of energy reduction and recovery technologies and general management culture. In the attempt to quantify CO_2 emissions from iron- and steel-making data collated from energy and CO_2 intensities were used in calculations taking into account world iron and steel production, from processes utilizing coke ovens, blast furnaces (BF) and basic oxygen furnaces (BOF), as well as electric arc furnaces (EAF), open heath furnaces (OHF) and direct reduction iron (DRI). It must be pointed out that the data do not include mining and transportation emissions, which contribute 0,05 t CO_2 / t_{cs} and 0,1 - 0,2 t CO_2 / t_{cs}, respectively [5].

ENERGY CONSUMPTION

The production of iron and steel consumes large quantities of energy, with significant variations in energy efficiency of primary steel production amongst plants and countries. These variations, which can reach up to 50 % [5], are attributed to plant size and consequently the amount of steel produced, the quality of iron ore, the level of waste energy recovery, as well as novel

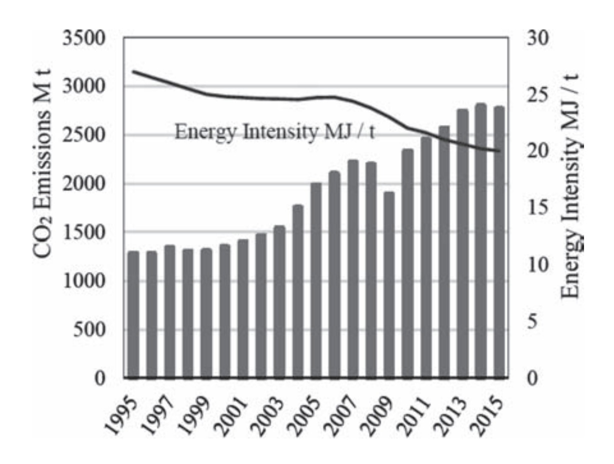

Figure 1 Energy intensity [6] and world CO_2 production [own calculations], from the iron and steel industry

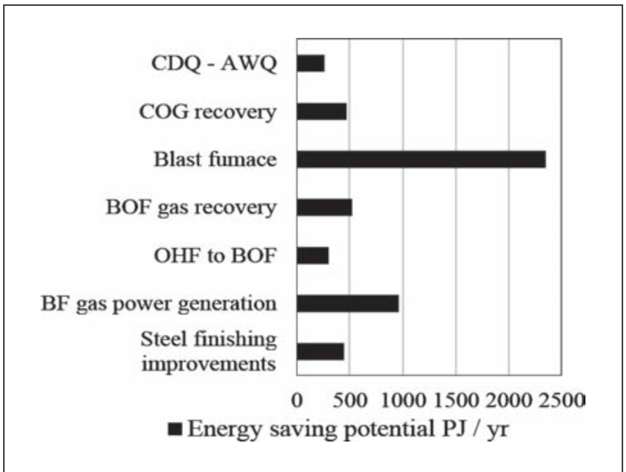

Figure 2 Energy saving potentials from applied technologies [5, 7] CDQ - AWQ: coke dry or advanced wet quenching, COG: coke oven gas

technologies implemented. Nevertheless, the energy used for the production of a ton of steel has decreased by 60 % in the last 50 years (Figure 1), reaching an average energy intensity of 20 GJ / t crude steel (t_{cs}), with a potential for improvement of 15 – 20 %.

Efficiency has also improved substantially over the last twenty-five years in many countries, but this has not had a significant impact on the world average, since nearly half of global iron production takes place in China, India, Russia and Ukraine, which have an average efficiency significantly lower than that of OECD countries. Studies [5-8] describe novel technologies that reduce energy consumption increasing energy efficiency. Figure 2 elaborates the estimated energy reduction potential of these technologies.

The blast furnace process including the hot stove, consuming 10 – 13 GJ / t_{cs} of energy, can benefit substantially by interventions described above. In addition, sintering, coke making and steel rolling consuming 2 – 3 GJ / t_{cs}, 0,75 – 2 GJ / t_{cs} and 1,5 – 3 GJ / t_{cs}, respectively, have significant energy reduction potentials, according to IEA (2010) [9]. Electric arc furnaces require 1 – 1,5 GJ / t_{cs} energy, much less than the BF-BOF process and the DRI - EAF process, since the energy intensive ore reducing process is circumvented.

Natural resources, plant size and age, energy prices, environmental and energy policies, as well as system optimization, operating efficiency, and process changes dictated by country characteristics, influence energy efficiency [6].

CO_2 PRODUCTION

CO_2 emissions from iron and steel plants (27 % of manufacturing sector) [5], arise from the high production energy intensity, as well as the dependence on coal as a reducing agent and energy source. Figure 1 presents the estimated CO_2 emissions over the last 20 years, as calculated using yearly CO_2 emission intensities according to the production process and the quantities produced by each process, which add up to the reported worldwide steel production data. CO_2 intensities calculated were 1 632, 1 450, 1 100, 2 500, and 410 CO_2 Kg / t_{rc} for, present av. BF – BOF, advanced BF – BOF, DRI (gas) – EAF, DRI (coal) – EAF and Scrap EAF, processes respectively, in agreement with other studies [5, 8]. In Table 1 the amount of CO_2 produced and the contribution to total CO_2 emissions of a steel making plant, are presented. It is obvious that several processes account for high CO_2 emissions, which include the power, sinter strand pellet and coke plants, as well as the blast furnace process.

Table 1 **CO_2 emissions from iron and steel making processes [5]**

Process	CO_2 / Kg / t_{rc}	CO_2 in flue gas / vol. %	Total CO_2 emissions / %
Lime kiln	57	30	3,1
Coke plant	285	25	15,7
Sinter strand pellet plant	288	5 – 10	15,9
Blast furnace	329	25	18,1
Power plant	709	20	39,1
Hot strip mill	84	10	4,6
Flaves etc.	63	0	3,5

In 2015 73,7 % of world steel was produced using the BF - BOF process, indicating that CO_2 production is linked to the production of steel, and any new mitigation measures have limited reduction potential, as shown by the white lines, in Figure 3. More precisely, CO_2 emission reductions achieved with CO_2 – free electrical power can account for a 8,9 % reduction in CO_2 emissions for the present av. BF – BOF process, 10,7 % for the advanced BF – BOF process, and 7,8 % from DRI (coal) – EAF. More substantial reductions can be expected for DRI (gas) – EAF (38,6 %) and Scrap EAF (36,6 %) processes, both however, suffering from the availability of low cost DRI and scrap, respectively.

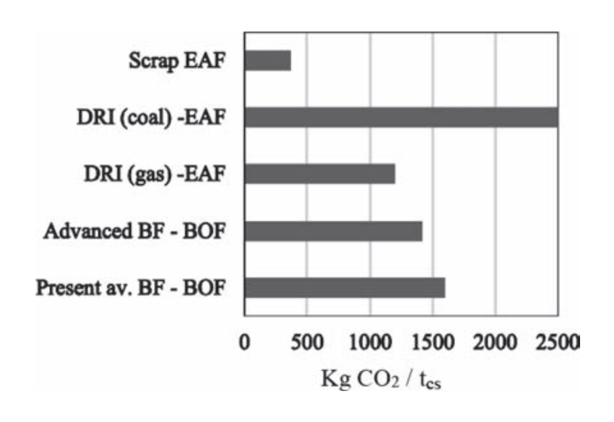

Figure 3 CO_2 intensity by process and reduction potential [10]

CO_2 CAPTURE AND STORAGE (CCS)

The work of Kundak et al [8], and data presented here, reinforces the fact that, if a significant CO_2 emissions reduction is sought, as the EU and COP 21 demand, carbon capture and storage (CCS) or novel technologies must be implemented. In the Blue Map scenario, the International Energy Association (IEA) predicts that by 2020, 30,24 Mt CO_2 / y will be captured, this figure rising to 822,6 Mt CO_2 / y in 2050.

In integrated steel plants 85 % of CO_2 emission are present in three gas flows, blast furnace gas (BFG) around 70 %, COG 9 % and 7 % in BOF gas [11]. Normally these gases are re-used as low grade fuel, which may recover some energy, but still releases CO_2, also increasing the point sources that have to be tapped to capture the resulting CO_2.

CCS has been employed in the ULCOS top gas recycling-blast furnace (TGR-BF) which reuses the carbon monoxide (CO) and CO_2 gas, reducing coke consumption by ~ 20 - 25 % and achieving a 45 – 55 % reduction in the CO_2 which is removed using physical adsorption techniques or pressure swing adsorption (PSA) [11].

Under the ULCOS program a novel hot metal production process called HISARNA is being tested at Tata Steel's IJmuiden works. This smelting reduction technology eliminates sinter and coke production thus reducing CO_2 emissions point sources. Estimated CO_2 emissions reduction, using the HISARNA alone, is 20 %, whereas combined to CCS, a reduction of ~ 80 %, compared to a present av. BF, is achieved.

CO_2 capture is already used in the shaft-based DRI production process using coal or gas as the reducing gas. Midrex Technologies have evolved a process where-by CO_2 is captured from the shaft furnace offgas, before it is recycled to the shaft furnace for internal reforming and reduction with the natural gas used [11]. Also along these lines, ULCOS is currently developing "ULCORED", a process for the production of DRI using a similar shaft reactor, which in combination to CCS leads to at least 50 % reduction in the CO_2 footprint, compared to a conventional BF - BOF process.

CONCLUSIONS

Several practices have been presented, which have been introduced in the iron and steelmaking processes, leading to reducing energy intensity and CO_2 emissions. It has been pointed out that these measures can only attain a 15 % to 20 % reduction, thus recognising the necessity of decarbonising the industry. European steel producers in 2000, initiated the programme Ultra-Low CO_2 Steelmaking (ULCOS), which has selected three effective technologies for further development, all of which, when combined to CCS, can lead to a 50 % reduction of emitted CO_2 in line with recent institutional developments. Most studies agree that the cost of CCS is a complicated issue, since large scale applications have not as yet provided results on actual commercial operation. The costs of CCS are influenced by the location of the plant, energy and materials prices, carbon pricing, capital cost estimation and pay-back period, all differing significantly from state to state. It seems that applying CCS to the coal-based iron and steel industry is expensive and this might prohibit its commercial deployment. The importance of low cost carbon-free electricity has been stressed in this and other studies, as an effective way to lowering CO_2 emissions in existing plants, as well as introducing novel technologies using hydrogen in the steelmaking industry [8]. The targets set in the EU's climate and energy framework, clearly influence the industry, and it is believed that through the European Carbon Trading System, economic incentives for the implementation of CCS and other CO_2 abatement technologies will emerge.

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Note: The responsible translator for English language is Budianu Marcu Alina Viorica, Târgu-Jiu, Romania.