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Direct Reduction Technology as a Flexible Tool to Reduce the CO_2 Intensity of Iron and Steelmaking

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Abstract: The transfer of our fast growing society from a carbon based to a low carbon based economy/production within the next decades is the global megatrend which has been discussed now for many years. The target of minus 80 % can only be achieved by a transfer of the global energy system. Today we have a portfolio of technologies available to reduce the CO_2 intensity further, but, without consideration of the two limitations of plant lifetime and carbon lean energy, a successful transfer will not be possible, and every company and country has its own timeline for this process. The forced use of natural gas can act as a bridge technology for the transfer between the energy systems. HBI and DRI allow a broad flexibility for the EAF steel production route as well as for the integrated BF/BOF steel production. The start-up of the voestalpine DR plant in the US is an important step to meet the challenges of the next decades.

Keywords: Steelmaking routes, CO_2 intensity, EU Low Carbon Roadmap, ULCOS, Direct reduction, HBI, Blast furnace

Direktreduktionstechnologie als flexibles Werkzeug zur Reduktion der CO_2 Intensität der Eisen- und Stahlerzeugung

Zusammenfassung: Der Umstieg unserer schnell wachsenden Gesellschaft von einer kohlenstoffbasierten auf eine kohlenstoffarme Industrie/Produktion innerhalb der nächsten Jahrzehnte ist zu einem wichtigen globalen Megatrend geworden.

Das sehr ambitionierte Ziel einer CO_2-Reduktion um 80% kann nur durch eine globale Energiewende erreicht werden. Mit den bereits existierenden Technologien ist eine Verringerung des CO_2 Ausstoßes möglich, allerdings müssen Anlagenlebensdauer und Verfügbarkeit kohlenstoffarmer Energieträger berücksichtigt werden. Dafür hat jedes Unternehmen und jedes Land seine eigenen Zeitvorstellungen. Der verstärkte Einsatz von Erdgas kann als Brückentechnologie zwischen kohlenstoffbasierter und kohlenstofffreier Produktion gesehen werden. Vorreduzierte Eisenträger wie HBI und DRI können vielfältig bei der Elektrolichtbogen wie auch bei der klassischen integrierten Route über Hochofen und LD-Prozess zur Stahlherstellung eingesetzt werden. Die Inbetriebnahme der voestalpine Direktreduktionsanlage in den USA ist ein wichtiger Schritt, um der Herausforderung einer CO_2 reduzierten Produktion in den nächsten Jahrzehnten zu begegnen.

Schlüsselwörter: Varianten zur Stahlerzeugung, Direktreduktion, ULCOS, HBI, Hochofen, CO_2 Reduktion, EU Fahrplan CO_2 Reduktion

1. Introduction

Megatrends are the challenges for the future of the iron and steel metallurgy. The global change in material production since the beginning of the 21st century has reduced the share of the EU producers to approx. 10 % of world production. Therefore, the main driver in the competition is technology development, which can be shown by different international benchmarks, e.g. CO_2 intensity. Within the last 50 years, the energy consumption has been reduced by 30 %, but now the thermodynamic limits are close to the consumption levels and it will get harder to get a significant reduction level. A further megatrend is the transfer from a carbon based to a low carbon based economy/production within the next decades.

Steel is essential for the modern world. Thanks to its strength and its properties of formability, it is one of the most versatile and adaptable engineering materials. It is the material of choice for a wide range of applications ranging from the construction of bridges and buildings to auto-

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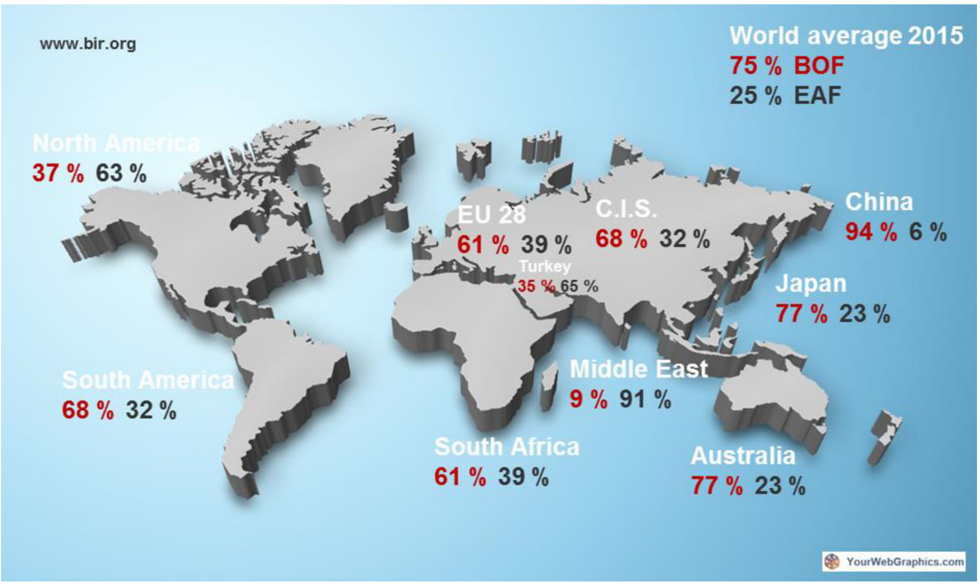
Fig. 1: Regional difference of production processes



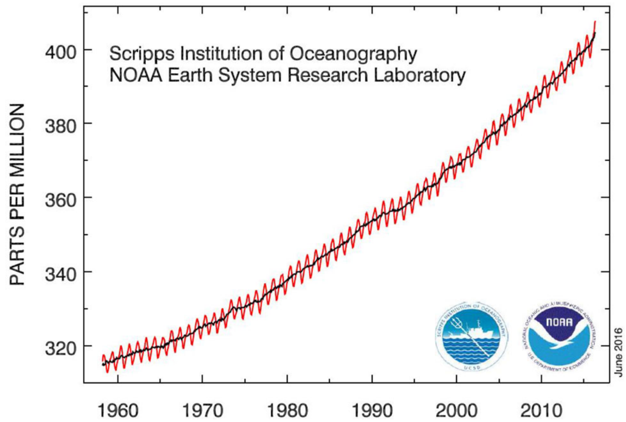


Fig. 2: CO_2 trend in the atmosphere [4]

motive and machine parts as well as packaging of food, generation of power, and uses in aerospace engineering. The major end-use industries include construction (35 %), automotive (18 %), and mechanical engineering as well as metal goods (14 % each). Steel's recyclability also makes it a key material for sustainable development [1].

2. Iron and Steelmaking Technology

Two general methods – BOF and EAF route – of crude steel production exist in the 21st century (Figure 1). The BOF route converts iron ores to steel via blast furnaces (BF) or smelting reduction (SR) processes and basic oxygen furnaces (BOF). The EAF route converts steel scrap or direct reduced iron (DRI/HBI) from reduction processes to steel via electric arc furnaces (EAF). Scrap can be melted to directly produce new steel. However, iron ores, which are iron oxides with an iron content of above 60 %, must first be reduced into iron. This means extracting the iron by removing the oxygen bound to it with the help of reducing agents mainly carbon monoxide CO and also hydrogen H_2.

This reduction step is the most energy intensive step in iron and steelmaking and consumes approx. 90 % of the primary energy demand for the production of steel. European Union crude steel production is today almost entirely divided between the BF-BOF and the Scrap-EAF routes. In 2015 BF-BOF accounted for 61 % of EU27 production and Scrap-EAF for the remaining 39 %. Although other iron- and steel-making processes (e.g. the COREX®/FINEX®-BOF route or the DR/EAF route) are used in different parts of the world, they have little to no significance for the European Union [2].

3. CO_2 Intensity and Global Emission Trends

The most common primary production route uses the BF in combination with the BOF. The best available technology (BAT) benchmark in Europe for emission of the blast furnace route is at 1475 kg CO_2 per ton crude steel (CS). Due to continuous optimization, the industry is already approaching the theoretical minimum of 1371 kg CO_2/tCS. Therefore, a substantial emission reduction is only possible through the implementation of new breakthrough technologies. Key areas of process development are Carbon Capture and Storage (CCS) or Use (CCU) in combination with fossil fuels and hydrogen as innovative reducing agents for the reduction process [1].

Depending on the separation of iron and oxygen, the iron and steel industry, one of the energy-intensive industries, is expected to contribute to the climate targets and to reduce GHG emission significantly by 2050. E.g. the German iron and steel industry consumed 6 % (554 PJ) of the total German end-use energy demand and caused 4 % (41 Mt CO_2) of the total GHG emissions in 2011 [3]. Since the preindustrial era, the concentration of greenhouse gases

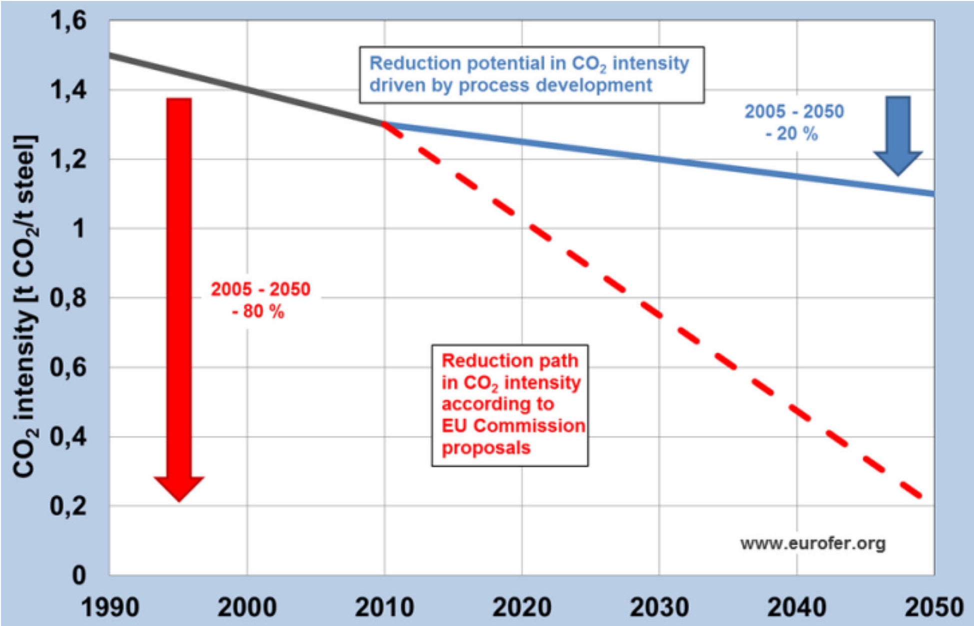


Fig. 3: CO_2 reduction path in the EU Roadmap [5]

(GHG) in the atmosphere [4] has risen steadily from below 300 ppm (1900) to 400 ppm in May 2013 (Figure 2).

In order to maintain a chance to keep global warming below 2.1 °C compared with the preindustrial age, the maximum threshold is considered to be 450 ppm and would be reached in 30 years at current emission levels. A drastic emission reduction is necessary across the world to achieve this target. As suggested by the Intergovernmental Panel on Climate Change (IPCC) for developed countries, the EU aims to reduce GHG emissions 80 to 95 % by 2050. This target is in line with the recommendations to decrease global emissions by 50 percent.

That roadmap for a competitive low-carbon economy by 2050 examines possible cost-efficient paths toward reducing European Union domestic GHG emissions by 80 % by 2050 (Figure 3). According to the commission's report, European industry would have to cut back its emissions below 1990 levels by 34 to 40 % by 2030 and by 83 to 87 % by 2050. In this context, the commission and the European Parliament invited industrial sectors to develop their own low-carbon roadmap. Studies confirm that the EU commission target without a radical transfer of the energy systems is far beyond the reach of the steel sector. In the economic ways, only 10 % emissions reduction per ton of steel are possible between 2010 and 2030 and 15 % between 2010 and 2050. There is also a very high CO_2 mitigation potential from innovative technologies in which steel cannot be replaced by any other material, indicating that European climate targets can hardly be reached without steel [5].

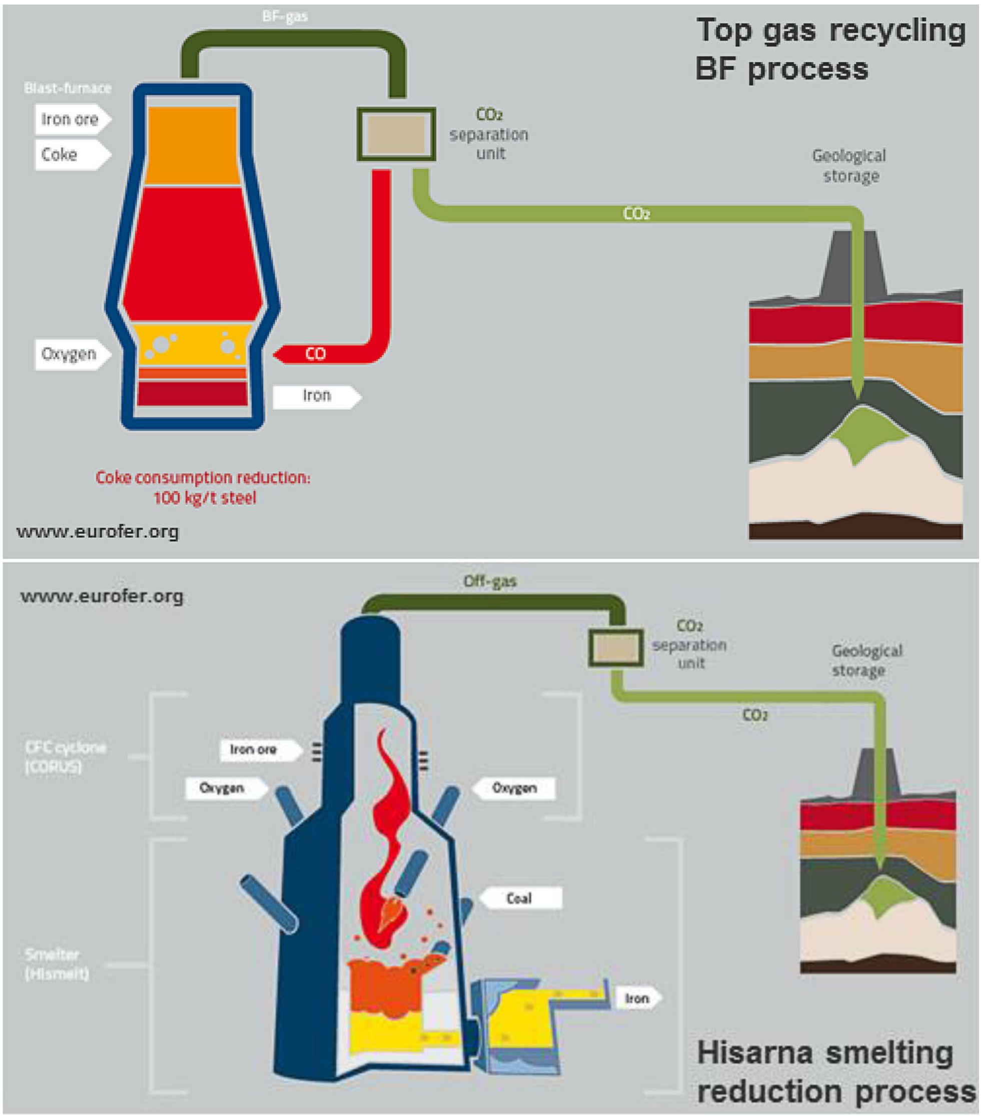
4. Technology Trend

If the steel industry is to continue producing in Europe and to decarbonize while retaining its global competitiveness, further substantial research has to be done. Carbon-lean technologies for reducing massive emissions even further have been the subject of a number of scientific studies and programs in recent years. The ULCOS program, set up in 2004, has made a major contribution to the issue. The initiative, which includes major European steel producers, was supported by the European commission. It has evaluated the technical CO_2 reduction potential of over 80 existing and potential technologies, out of which it identified technologies with a long-term emissions reductions potential of more than 50 % e.g. BF with top gas recycling (BF-TGR), bath smelting (HISARNA), and direct reduction (Figure 4).

These technologies have to be investigated in detail with R&D programs including pilot and demonstration plants. All breakthrough technologies rely on the development of CCS and/or the transfer from carbon to hydrogen as a reducing agent to unfold their full abatement potential.

In the further decades of our century, the traditional model of the integrated steelworks, taking in iron ore as a raw material and reducing it to metallic iron, will be facing a challenge (Figure 5). This is the further growth in world steel production. Since the year 2000, the amount of steel made per year has doubled from 800 Mt to 1.6 Bt now. There is something quite important about the last fifteen years of steel production, compared with everything that went on before. Fifteen years is about the time constant for steel's entry into the scrap cycle [6]. Starting from scrap and using the electric arc furnace (EAF) rather than the blast furnace is a significant change to make steel in carbon footprint terms. As long as scrap is fairly scarce, though, economics will tend to the primary BOF route. But what happens when the new steel enters the scrap chain and a transfer from carbon to renewable energy takes place? There could be the shift towards EAF metallurgy for new units and a more or less constant level of BF/BOF units.

Fig. 4: Ironmaking technology with CCS [5]



5. Combination of Process Routes

The production units in iron and steelmaking have a lifetime over more decades. Therefore, a technology change can only be done when a new investment is planned. The second limitation is the availability of renewable or carbon lean energy on a continuous base over 8500 h per year. This is not in the influence area of the metallurgical industry. Today we have all technologies available to reduce the CO_2 intensity further, but, without consideration of the two limitations of plant lifetime and carbon lean energy, a successful transfer will not be possible, and every company and country has its own timeline for this process.

Almost all existing blast furnace plants in the world have the latest technical standards and will produce until the middle of the century. Apart from the classical scrap route, the DR/EAF route could be a new approach for an integrated plant in the future.

Figure 6 shows a comparison of the CO_2 emissions for the two core process routes existing worldwide. Core process means the reduction of iron oxide and/or the melting of the metallic phase without the pretreatment of the iron oxides (sintering, pelletizing) and the production of coke. The iron containing material for the two shaft processes are pellets.

The forced use of natural gas in the integrated DR/EAF route reduces the CO_2 emission by 35 % from the baseline BF/BOF process with no limitations in the product portfolio. The DR process is also the guarantee that, in a society based on renewable energy and hydrogen, the CO_2 emission can be reduced to almost zero when the natural gas is replaced by hydrogen.

The potential for HBI to be used in the BF/BOF steelmaking route, rather than just the EAF-based steelmaking with which the use of DRI is usually associated, could be the advantage for a future European iron and steelmaking under the target of CO_2 reduction. The use of HBI also works with limited hot metal capacities, and the smaller carbon footprint of an integrated steelworks using HBI could prove attractive to other steelmakers worldwide, too (Figure 7).

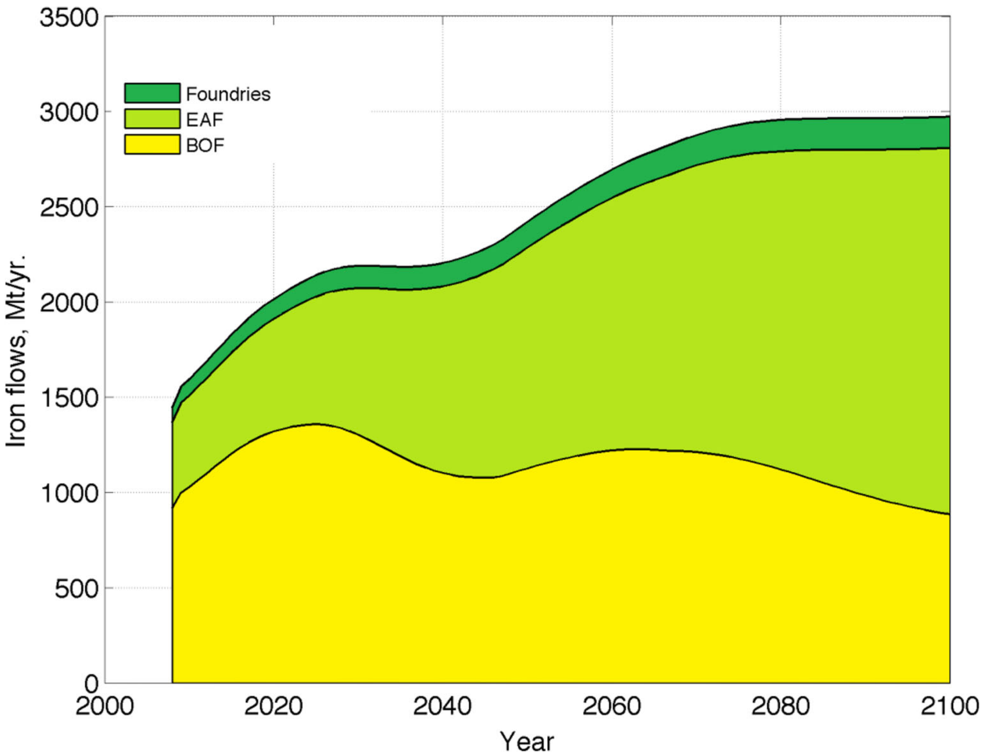


Fig. 5: Developments in world steel production [6]

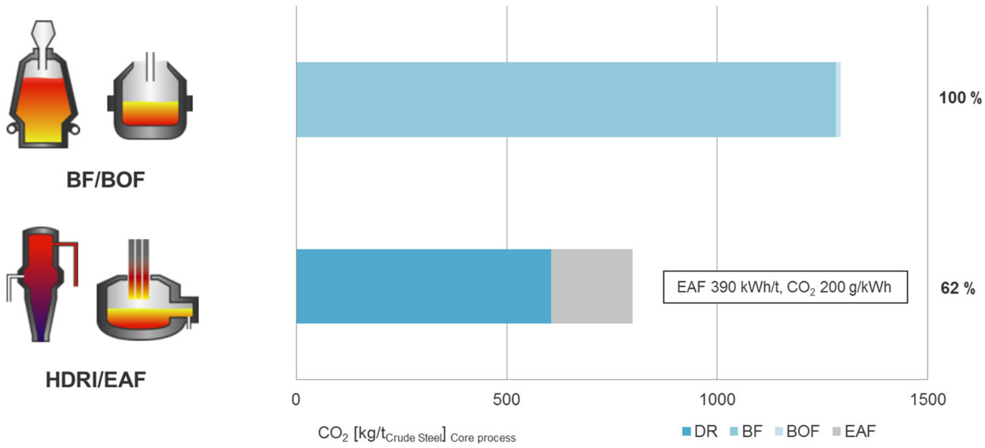


Fig. 6: CO_2 emissions of the core processes for steelmaking

This story is not new. HBI has been used successfully by steelmakers in the USA for 25 years, so there is no technology risk associated with using it compared with breakthrough technologies like TGR-BF and Smelting Reduction

Under consideration of all these trends in iron and steel metallurgy in the next decades, what could now be the strategy for a new production unit? A possible answer can be found in the decision by voestalpine for a HBI plant in Texas, USA, to produce iron metallics for its BF/BOF steelworks in Europe and as a source of merchant product to sell to other steelmakers (Figure 8). The 2.0 Mtpy MIDREX® DRI/HBI module, the largest of this process type in the world, is being seen as a landmark development. The US natural gas prices, the excellent location, and the market potential in the NAFTA region were key factors in the decision.

A consortium of Primetals and Midrex Technologies was awarded for the supply of Equipment, Engineering and Technical Services of the Direct Reduction plant as greenfield project. The Midrex plant, which consists of a 7.15 meter reduction shaft and a 20-bay reformer, is equipped with a Köppern hot briquetting system combined with hot fines recycling. The cooling of HBI is done by cooling conveyors. A further benchmark is the first recycling plant worldwide based on cold briquetting process for iron containing by products, like fines, dusts and sludges. These briquettes will be charged back to the reduction process. The expected HBI product characteristics are an average metallization degree of 93 % and 1.5 % carbon by a DR process natural gas

Fig. 7: HBI as input material in the BF process

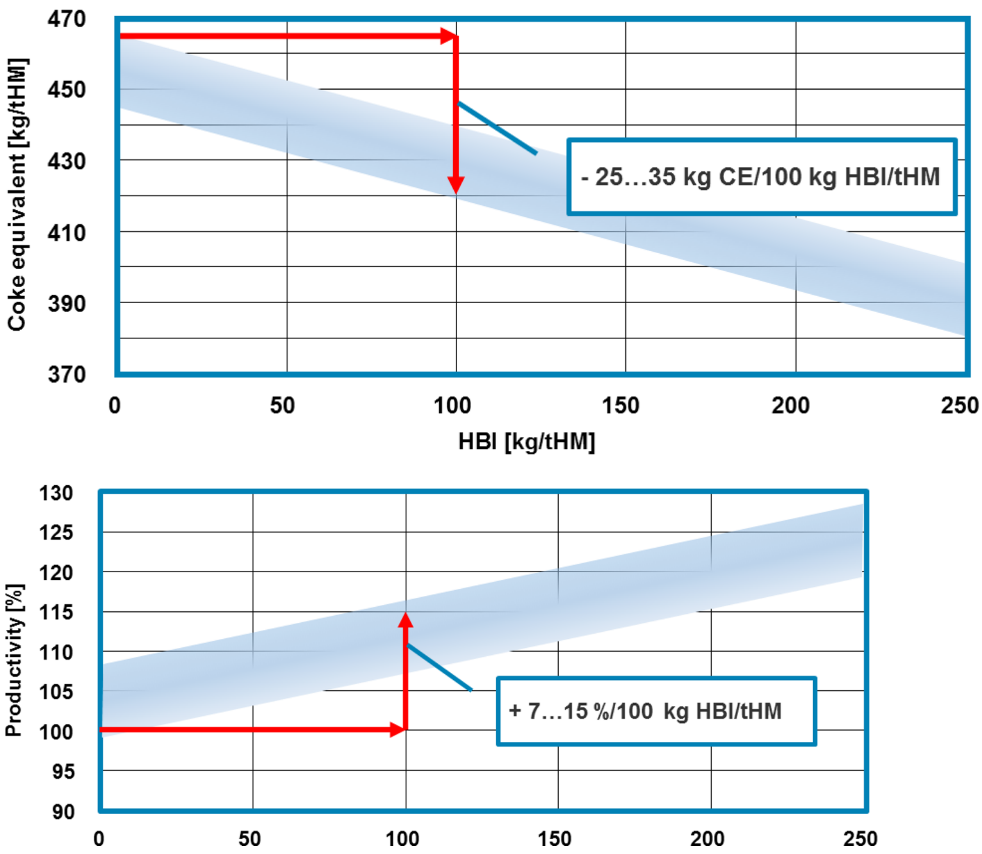


Fig. 8: Direct reduction plant in Corpus Christi, TX

consumption of 10.05 GJ/tHBI. After current commissioning activities including integrated plant tests and dry-out, the Midrex plant is started up in the third quarter of 2016.

6. Conclusion

European Union crude steel production is today almost entirely divided between the BF-BOF and the Scrap-EAF routes. Depending on the separation of iron and oxygen, the iron and steel industry, one of the energy-intensive industries, is expected to contribute to the climate targets and to reduce GHG emission significantly by 2050. All breakthrough technologies developed by programs like ULCOS rely on the development of CCS and/or the transfer from carbon to hydrogen as a reducing agent to unfold their full abatement potential. The forced use of natural gas can act as a bridge technology for the transfer between the energy systems. HBI and DRI allows a broad flexibility for the EAF steel production route as well as for the integrated BF/BOF steel production.

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