THE BLAST FURNACE IN VIEW OF PAST, CURRENT AND FUTURE CO2 SAVING TECHNOLOGIES *

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Abstract

Blast furnaces are widely employed today for iron production all around the world, with a total production of around 1.2 billion tons per year. Its operating principle, which relies on usage of coke to reduce the ore, to ensure the permeability in the reaction vessel, to maintain its flexibility of operation and acceptability for varying qualities of iron ores. The blast furnace route is widely considered as the most economic and efficient route of iron production, however it is based on fossil energy carriers. The blast furnace route has undergone significant developments in terms of energy efficiency in the last decades, which led to a substantial reduction in the use of fossil reduction materials. Being an energy intensive process, competitiveness and cost saving in the blast furnace plant was always strongly related to the saving of energy and hence reduction of CO2 emissions. In addition to this, EU emissions trading system (EU ETS) as a cornerstone of the EU's policy in response to climate change has set new “challenges” for iron production in Europe. Paul Wurth has always been deeply involved in the development of energy saving technologies for blast furnaces. In the following a review of energy saving achievements developed in the last decades will be presented and the potential of available CO2 saving technologies will be summarized. Additionally, an outlook about the potential of future technologies, concepts and their impact on the blast furnace and the steel plant’s energy balance will be discussed. Finally, the replacement of carbon by hydrogen as reduction agent in the steel plant will be reviewed, with special focus on a comparison of costs and incentives.

Keywords: CO_2 emission; Iron and steel making; Blast furnace process; Energy saving technologies; Hydrogen steel making; Carbon capture and storage; Carbon capture and utilization; Carbon direct avoidance; CCS; CCU; CDA.

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1 INTRODUCTION

The iron and steel industry is based on energy intensive processes, which are a source of significant industrial CO_2 emissions. The conventional BF-BOF route is considered as the most successful and economic production route, hence it is regarded as a prime choice for mass production of various steel products, representing more than two third share of the total crude steel production in the world.

To comply with the latest objectives on greenhouse gas (GHG) emissions set by the agreements of the “Conference of the Parties” (COP), significant additional effort is required to achieve the targeted CO_2 emission reduction in steel plants. Apart from CO_2 saving, reduction in the primary energy use by improvements in energy efficiency and integration of renewable power share has substantial priority for the future targets.

As other routes of steel making lacks many techno-economic advantages associated with the BF-BOF route, and new ironmaking technologies are either at early stages of development or facing major technical as well as economic challenges, steel production via BF-BOF routes is expected to remain dominant in the upcoming decades, with incremental technological upgrades for CO_2 emission abatement.

The present paper reviews different technological developments around the BF iron making route in view of past and current CO_2 savings, and analyses possible ways to reduce even further the CO_2 emissions from the BF route for the future.

CO_2 saving technologies in view of past
Although the motivation behind the technological developments of the blast furnace process has changed according to the constraints existing in the different periods of its history, continuous improvement connected to reducing coke consumption has always been at the center. The fuel rate reduction in the BF, especially in Germany, took place mainly from 1950 to 1980, from more than 1000 kg/tHM to around 500 kg/tHM with the corresponding reduction in the CO_2 emissions (1). These developments were mainly attributed to the use of higher quality raw materials, higher blast temperature (>1200°C), oil injection coupled with oxygen enrichment and introduction of top pressure for the BF.

Since 1990, no substantial fuel rate reduction took place since the efforts in this period were focused on coke rate reduction through increased use of PCI injection (2). Although the motivation was connected to cost savings, replacement of coke in terms of PCI helped in CO_2 savings as PCI has a lower CO_2 emission factor compared to coke. Today PCI injection rates as high as 200 to 250 kg/t_{HM} and coke rates as low as 300 to 250 kg/t_{HM} are common practice in some of the blast furnaces in Western Europe.

The development of the Bell less top charging (BLT) has been a remarkable achievement in the BF technology. Integration of BLT in the BF led to coke as well as CO_2 savings through different effects such as BF process optimization, prevention of furnace irregularities, and lead to the possibility for effective utilization of by-products such as nut coke, BOF slag etc. in the BF.

Here below are listed some of the major technological developments, which have been integrated within the last decades in a majority of the blast furnaces in Europe. Most likely only blast furnaces equipped with these technologies and operation approaches will be able to cope with the challenges resulting from future CO_2 saving requirements:

1. Bell less top charging equipment (BLT)
2. O_2 enrichment of hot blast
3. Higher hot blast temperature
4. Injection of auxiliary fuel such as PCI, natural gas etc.
5. Improvement in quality of raw materials quality
6. Reliable tapping technology
7. Instrumentation and automation

2 PRESENT CO2 SAVING TECHNOLOGIES

Considering the CO_2 certificate price development over the past few years and its forecast, implementation of the latest available energy and CO_2 saving technologies will not only significantly contribute to reducing the CO_2 footprint of the steel plant, but will most likely bring economic advantages for the operators.
We provide in the following an overview of important CO_2 saving technologies available in the field of blast furnace based ironmaking.

2.1 Coke dry quenching CDQ

Coke dry quenching technology enables the recovery of the sensible heat from hot coke by means of quenching with nitrogen or a mix of inert gases. The recovered heat can be used for the production of electricity or for other purposes.

Unlike wet quenching, the losses of carbon due to the reaction with water as well as associated environmental pollution are less in case of CDQ. Dry quenched coke has very low moisture content which ensures positive impact in the energy balance of the BF shaft, especially for the blast furnaces operating with low top gas temperature. Dry quenched coke has lower coke reactivity index (CRI) and higher coke strength after reaction (CSR) compared to wet quenched coke. Owing to all these advantages, CDQ facilitates coke saving in the BF in addition to energy recovery in the coke plant

2.2 Waste heat recovery system in sinter plant

There are two major sources of waste heat that can be used for energy and CO2 saving in the sintering process.
First, the sensible and chemical energy of the waste gas can be partially recovered by recirculating it back to the sinter bed. This leads to reduction of coke consumption and consequently CO2 emissions. The second source of waste heat is the hot air exhausted from the sinter cooler. Different possibilities exist for recovering this sensible heat. Some common examples are the use of the hot air as preheated combustion air for the ignition hood burners, partial recirculation to the sinter bed in combination with the waste gas recirculation, pre-heating of the raw mix feeding the

sintering process or the production of steam combined or not with the production of electricity.

2.3 Top pressure recovery turbine (TRT):

A significant portion of BF top gas kinetic energy can be recovered in the form of electricity by TRT. TRT facilitates the recovery of around one third of the power used by the BF blower. Even though the pressure of the blast furnace gas is low, the high top gas volume makes the utilisation of TRT's worthwhile. PW has also proposed several possibilities for increasing the energy recovery from the top gas by integrating waste heat recovery in the TRT installation.

2.4 Waste gas heat recovery system (WGHRS) of BF stoves

WGHRS of hot blast stoves is based on the principle of recovering sensible heat from stove waste gas, through external heat exchangers. The recovered heat is used to preheat the combustion media during the heating phase of the stoves. This leads besides to an increased energy efficiency of the stove plant to savings of enrichment fuels such as coke oven gas (COG) or natural gas (NG). These fuels are costly and shall rather be used for metallurgical purpose leading to CO2 mitigation.

2.5 Coke oven gas (COG) injection in the BF

COG, being rich in calorific value (16 -18 MJ/Nm3), is a good source of energy for the substitution of coke in the blast furnace. COG can preferably be injected in the BF tuyere.

COG injection at tuyere level is a known technology and is relatively easy to implement. PAUL WURTH is working with several customers for tuyere COG injection, applying different technologies, such as COG injection via port or via separate lance. According to current BF operation scenario, COG injection in the tuyere together with high PCI injection (~200 kg/t_{HM}), can lead to around 3-4% of CO_2 savings (3).

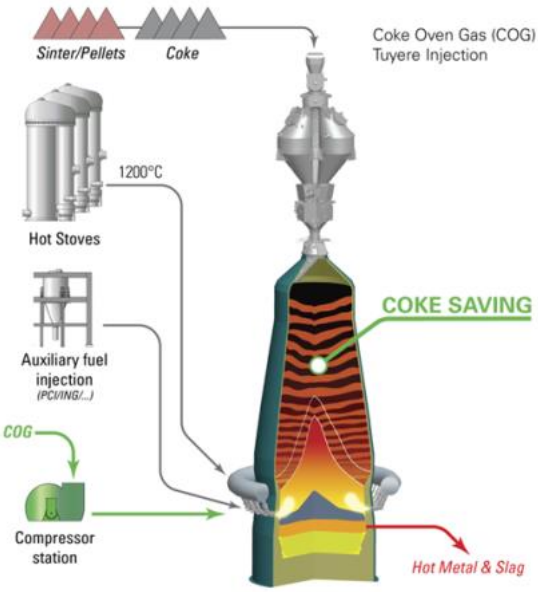

Figure 1: Tuyere COG injection concept

2.6 Advanced process automation tools and instrumentation:

BF operation at high performance under varying process conditions necessitates in-time control of every aspect of the process. An early detection of phenomena which could perturb the blast furnace and a swift adaptation to variable operating conditions have an immediate positive impact on fuel consumption as well as CO_2 savings (4).

Paul Wurth and TMT are working together in the developments of BF process automation tools and instrumentation to ensure a more accurate process control in accordance with varying process conditions as well as raw material quality. Many of such developments are readily available such as: BFXpert™, TMT SOMA™, TMT 3D TopScan™ (5; 6). Integration of such advanced instruments and process control system for monitoring and optimization of BF process ensures savings in carbon based fuels and consequently CO_2 emissions from the BF.

2.7 Improved burden mix:

Raw material quality has a significant influence on the energy as well as fuel consumption of the BF. Today many European blast furnaces are operating with high sinter proportion in the BF charge (7). As sinter production involves higher CO_2 emissions than pellet production, an increased share of high quality pellets in the BF burden mix is an interesting option for steel makers to decrease CO_2 emissions. This can be economically viable if CO_2 certificate prices offset the increased burden cost with high pellets.

Nevertheless in spite of having a higher CO_2 footprint compared to pellets, the sintering process is essential to effectively utilize the generated fines within the boundary of the steel plant. Therefore, sinter shall be part of the burden mix to a minimum amount, compatible with the reuse of fines generated by the steel production process.

Similarly, addition of pre-reduced raw materials such as direct reduced iron (DRI) or hot briquetted iron (HBI) could lead to a reduction in fuel consumption as well as CO_2 saving from the BF, along with the other advantages such as productivity gain, lower slag rate etc. Addition of DRI/HBI having metallization degree usually higher than 90%, signifies that the iron reduction will be done outside the BF leading to lower energy consumption within the BF. Comparison of typical BF operation with high sinter in contrast to BF operation with high pellets and with Green HBI charging is given in **Table 1,** where CO2 saving is indicated for complete BF plant which includes coke oven plant, sinter plant, pellet plant and blast furnace.

High proportion of acid pellets necessitates high limestone additions in the charge, which ultimately leads to higher fuel rate as well as CO_2 emission from the BF. Therefore optimization of burden mix with respect to raw material and target slag basicity is necessary.

BF process parameters		**Units (STP)**	**Refere-nce case**		
				High Pellet	**Green HBI (200 kg/t_{HM})**
	Sinter	%	67	33	57,8

Burden mix	Pellet	%	33	67	26,6
	HBI	%	0	0	12,8
Top gas	Volume (dry)	m^3/t_{HM}	1.478	1.469	1.254
	Temperature	°C	163	154	126
	Top gas LHV	MJ/m^3	3.323	3.143	3.498
	Total chemical energy	MJ/t_{HM}	4.912	4.617	4.386
	Eta CO	%	48,6	52,3	47,8
Fuels	PCI rate (dry)	kg/t_{HM}	180	180	180
	Total dry coke rate	kg/t_{HM}	300	294	239
	Total Coke saving	kg/t_{HM}	-	6	61
Race-way	Gas volume	m^3/t_{HM}	1.360	1.331	1.173
	RAFT	°C	2.150	2.150	2.150
	O_2 injection	Nm^3/t_{HM}	47,8	50,3	58,1
	Natural blast	Nm^3/t_{HM}	947	919	778
	Slag rate	Kg/t_{HM}	257	203	226
	% CO_2 saving from BF plant in comparison to reference operation		-	5,8	14,8
	Possible productivity gain (%) in comparison to reference operation		-	6,3	12,7

Table 1: Typical BF operation with high sinter in comparison to BF operation with high pellet and HBI charging

FUTURE CO_2 SAVING TECHNOLOGIES

Today the best preforming blast furnaces, equipped with most advanced technologies and operational practices are operating close to the thermodynamic limits. The energy consumption of these best performing blast furnaces amounts to about 16 GJ per ton of hot metal, which is just about 7% above the thermodynamic energy requirement (1). Additionally, the space for improvements, for example in the cooling losses of the blast furnace is rather limited. Therefore, potential for further CO_2 saving through improving energy efficiency of such best performing blast furnaces are very limited.

Despite this high energy efficiency the BF route has still huge potential for further CO_2 emission reductions. The brief analysis of both, the energy consumption as well as the energy input into the blast furnace (
Figure *2* and **Figure 3**) shows the potential of CO_2 savings that can be realised with the existing BF/BOF steel production route with relatively modest technological and operational changes. Whereas some technologies may even be OPEX positive, others will require different economic frame conditions for not jeopardising the competitiveness of the European steel production.

Figure *2* shows the energy consumption in a typical BF operation today. The reaction energy as well as the energy for sensible heat is defined by the nature of iron making, the sum of which is around 11 GJ/t_{HM}. It can be influenced by substituting the iron bearing material to a pre reduced form such as HBI or DRI. Alternatively, green pig iron, produced with CO_2 free char coal, could also be charged in the BF, however all these materials could possibly be considered in a more advantageous way in the downstream processes.

Around one third of the total energy input to the blast furnace exits the furnace with the BF top gas. This is due to the limitations arising from the Boudouard reaction at lower temperature (<900 °C) which does not allow the complete utilization of all input energy in the BF. Out of the total gas energy exiting the BF top, around one third is used again within the blast furnace process via heating of the stoves. The remaining two third is not utilized in the BF process due to its low specific energetic and reduction value, and is therefore commonly used in the power plant or steel shop for heating purposes. It is thus evident that the metallurgical utilisation of these remaining off gases in the blast furnace process has the potential of up to 20% CO_2 saving.

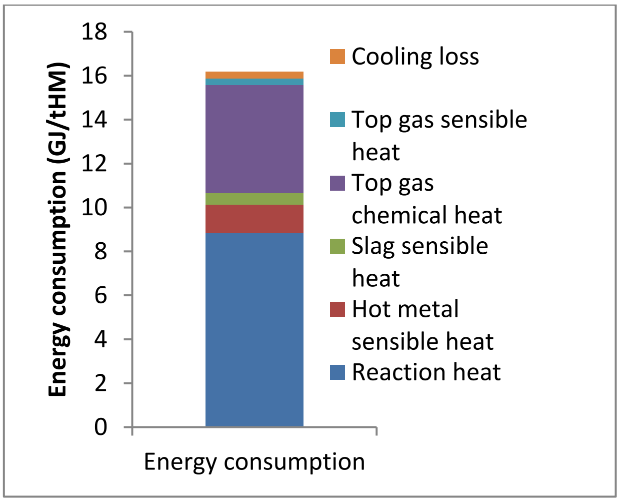

Figure 2: BF energy consumption analysis of the reference operation case from table 1

In the framework of ULCOS several technologies have been investigated for this purpose and top gas recycling and oxygen blast furnace coupled with CO_2 separation, capture and storage was proposed as one of the preferred way. However, it is still not considered as a viable option for steel makers due to associated economic as well as technical challenges and associated social acceptance. Another way is the process integration of the steel industry with other industries, as done in the European project “Carbon to Chem” in which the off gases of the steel plants are used for the fabrication of raw materials for the chemical industry. This approach however requires very specific industrial frame conditions not available at most of the steel plant sites.

Figure 3 shows the typical energy input in today’s high performing blast furnaces. One can see that approximately 50-60 % of the energy is coming from coke, 30-40 % from the auxiliary pulverised coal injection and the remaining 10 % are represented by the sensible heat of the hot blast resulting from the burning of a part of the top gas. This energy input cannot be modified freely since there are several constraints, mainly integrity of the burden and its permeability as well as flame and top gas temperature. Despite these constraints the blast furnace shows a strong flexibility allowing to adapt the fuel utilisation in view of CO_2 emission mitigation.

At today's energy and CO_2 certificate price level, a substantial reduction of CO_2 emissions can have positive impact on the steel production cost. The key is the substitution of coke by steel plant off-gases. This is limited however by the availability of these gases and the minimum coke rate required for the blast furnace operation. The substitution of PCI in current scenario is economically difficult as PCI today is a cheap energy source.

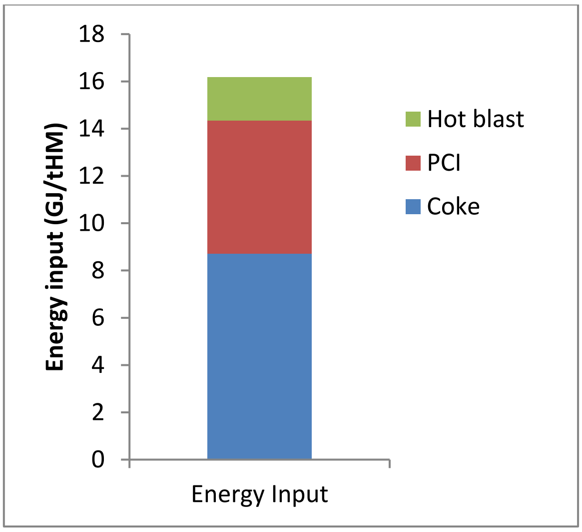

Figure 3: BF energy input analysis of reference operation case from table 1

The following section provides an overview of the various concepts that PAUL WURTH is investigating for future CO_2 emission abatement from the BF route in terms of BF process and its related CO_2 saving potentials.

3. Injection of fuel based on lower carbon content:

3.A. Natural gas (NG) injection as a replacement of PCI

NG has a 10-15% lower carbon content than PCI; therefore, replacement of PCI with NG has the potential for incremental CO_2 emission abatement from the BF, in case the economic advantage of PCI injection is countered by increased CO_2 certificate prices.

NG has higher coke replacement rate compared to PCI, however it requires higher oxygen enrichment due to the cooling effect on the flame temperature. This leads to a reduced injection amount compared to PCI. The highest NG injection rate achieved till date is 130 kg/t_{HM}, compared to 252 kg/t_{HM} for PCI (7). A comparison of BF operation with NG (CH_4) and H_2 along with high PCI (180 kg/t_{HM}), in terms of major BF process parameters and CO_2 saving is given in **Table 2**.

BF process parameters		Units (STP)	**Refer-ence case**		
				NG (CH_4)	H_2
Injectant	Maximum amount of injection	Nm^3/t_{HM}	-	43	134
	volume (dry)	Nm^3/t_{HM}	1.478	1.272	1.241

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Top gas	Temperature	°C	163	103	85
	Top gas LHV	MJ/Nm³	3.323	4.071	4.210
	Total chemical energy	MJ/t_{HM}	4.912	5.179	5.225
	Eta CO	%	48,6	49,9	50,6
Fuels	PCI rate (dry)	kg/t_{HM}	180	180	180
	Total dry coke rate	kg/t_{HM}	300	261	267
	Total Coke saving	kg/t_{HM}	-	38,9	32,8
	Coke replacement ratio	kg/kg	-	1,3	2,8
Race-way	Gas volume	Nm³/t_{HM}	1.360	1.228	1.222
	RAFT	°C	2.150	2.150	2.150
	O_2 injection	Nm³/t_{HM}	47,8	119	113
	Natural blast	Nm³/t_{HM}	947	653	619
	% CO_2 saving from BF plant in comparison to reference operation		-	3,4	6,5
	Possible productivity gain (%) in comparison to reference operation		-	10,6	12,5

Table 2: Typical BF operation with high PCI injection (180 kg/t_{HM}) in comparison to BF operation with NG and H_2 injection along with PCI at BF tuyere

3.B Integration of biomass in ironmaking

Biomass is considered as carbon neutral. Replacement of part of the PCI with bio-charcoal will lead to CO_2 emission reductions. Additionally Biomass can be added to the BF from the BF top as well and also in the production of sinter. Due to the big quantities of required biomass, the typical CO_2 reduction potential resulting from the integration of biomass, if not imported from countries with big biomass availability, is limited to the order of magnitude of 4 %. PAUL WURTH is pursuing technological alternatives for charcoal production allowing the environmental friendly production of a high performance char coal taking high value use of a given biomass.

4. Off-gas utilization for metallurgical purpose:

The generation of the process off-gases such as coke oven gas (COG), blast furnace gas (BFG) and basic oxygen furnace gas (BOFG) in a steel plant is much higher than their internal requirement as a fuel. The surplus of these process off-gases is mostly utilized in the power plant for the production of electricity. Power plants in steel industries normally have low thermal efficiencies and therefore even higher CO_2 emissions than coal based thermal power plants. Moreover, in some areas, cheaper electricity can be purchased from the external power grid due to politically driven specific incentives associated to its “green” production.

CO_2 emissions from steel plants can be reduced by using technologies allowing the utilization of surplus process off-gases for metallurgical purpose within the BF. COG injection in the BF is one of such technologies for short term CO_2 reduction. Consequently, PAUL WURTH is developing technologies not only for utilization of COG but also of COG along with the BFG in blast furnace. The electric energy shall be purchased from the external power grid and preferably from renewable sources.

4.A. Reformed COG shaft injection:
COG injection in the lower BF shaft is an alternative option to utilize higher amount of COG in the BF. Shaft injection does not limit the furnace operation in terms of Raceway adiabatic flame temperature (RAFT) and improves the top gas temperature due to increase in shaft gas volume. In case of COG injection at BF shaft, the temperature of the COG should be equivalent to the temperature of the lower shaft (900 -1000 °C), in order to not cool or overheat the shaft zone.

Heating of COG up to such high temperatures is associated with technological challenges such as carbon soot deposition as well as poisoning of reactor surface due to the impurities present in the COG. PAUL WURTH is therefore actively working on the development of COG shaft injection concepts. For further details on the COG shaft injection and influence on the BF process parameter, the readers are referred to our recent works in Ref. (3)

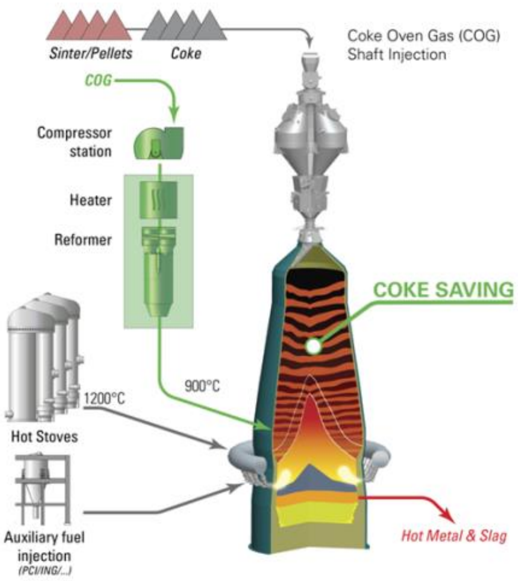

Figure 4: Reformed COG shaft injection concept

4.B. Dry reforming of COG:
Dry reforming is a well-known reaction of hydrocarbons with CO_2, which produces a H_2 and CO containing reducing gas.

CH_4 (g) + CO_2 (g) = 2CO(g) + $2H_2$ (g) ΔH_0 = 247 kJ/mol

Industrially dry reforming is usually carried out in presence of a catalyst at lower temperature. PAUL WURTH is developing technology to execute the dry reforming reaction at higher temperature level not requiring a catalyst which is typically prone to poisoning. Laboratory scale tests are being executed to define the best process conditions with this approach. The process is foreseen to be performed in a specially designed reforming regenerative heat exchanger (a suitably modified hot stove), which will convert the mixture of COG and BFG into hot syngas. The COG dry reforming hot stove will operate in a similar way as the conventional hot blast stove. The compressed COG and BFG will be reformed and heated up to a temperature between 900-1300°C. The generated hot reducing gas can be injected in the BF at tuyere as well as lower shaft level.

This technology provides the opportunity to exploit a significant amount of process off-gases in the BF. Dry reforming technology provides the possibility of stepwise CO_2 reduction from the BF plant with great CO_2 saving potential of 17–50%. A detailed overview can be found in our recent publication (3).

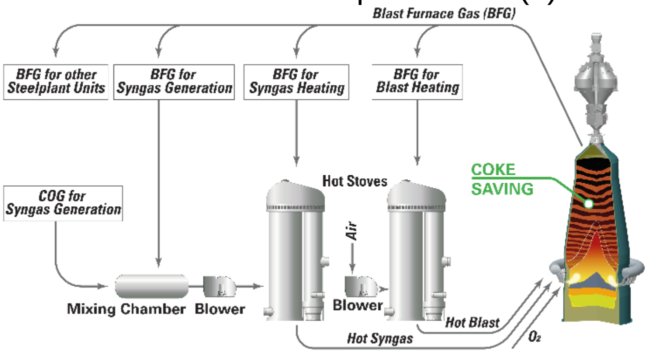

Figure 5: Dry reforming of COG with BFG

5. H_2 injection in the BF:
Hydrogen is likely the most powerful medium for the replacement of fossil fuels with renewable energy in the steelmaking industry. Several European steelmakers have already initiated projects for the use of hydrogen and also PAUL WURTH is pursuing its strategy for hydrogen as the main alternative fossil free energy carrier for the production of iron and steel. Whereas the complete carbon free steelmaking based on hydrogen reduced iron ores might be the final objective, the utilisation of hydrogen in the blast furnace as a reducing agent in increasing quantities can be seen as an intermediate stage to stepwise switch from the traditional iron making route to CO_2 free steel making.

H_2, being rich in calorific value (120 MJ/kg), has the potential for injection in BF tuyere as an auxiliary fuel, with PCI or even as a replacement of PCI. Injection of cold H_2 at the tuyere level along with high amount of PCI, >180 kg/t_{HM}, leads to a significant drop in the RAFT. Although RAFT can be improved with increasing amount of oxygen enrichment, the process becomes limited by the top gas temperature. Therefore, only a relatively small amount of cold H_2 can be injected into the tuyere, which limits the CO_2 saving potential of this technology to around 6-7 % for the BF operation with high PCI injection (>180 kg/t_{HM}).

Considering the future targets for CO_2 saving, replacement of PCI with H_2 could be an interesting alternative. For economic viability, this will require significant changes of green hydrogen cost and CO_2 certificate price. Complete replacement of PCI with H_2 will lead to rather limited CO_2 saving of up to 15%, as only a limited amount of H_2 can be injected at BF tuyere level (around 35 kg/t_{HM}), which leads to an increase in the coke rate compared to typical BF operation with high PCI injection. Nevertheless, shaft injection of hot hydrogen (>900°C) or even injection of hot H_2 at BF tuyere may allow even higher amount of hydrogen injection as well as CO_2 saving from the BF.

As hydrogen utilization in the BF is limited (8), increasing amount of hydrogen injection will lead to increase in the hydrogen content of the BF top gas, which has significantly lower economic value compare to hydrogen. Therefore, the recycling of BF top gas at shaft or tuyere level might be needed for the blast furnaces operating with high hydrogen in order to achieve effective utilization of injected hydrogen for carbon based fuel reduction from the blast furnaces.

In *Table 2*, injection of coke oven gas, natural gas and hydrogen is evaluated and compared with the reference case of conventional operation with high PCI injection. In the simulation, hydrogen is treated as a carbon neutral fuel.

Hydrogen injection in the BF is associated with technological challenges which need to be tackled and for which PAUL WURTH is engaged in developing technical solutions. One aspect is related to the high H_2 content of top gas, carrying the risk of explosion and thus requiring new safety concepts for the BF top equipment. Additionally, modifications in tuyere injection technology will be required allowing simultaneous injection of H_2 and pulverized coal as well as improvements to the shaft gas injection concepts integrating H_2 injection.

Furthermore, the technologies for the generation of renewable hydrogen are becoming efficient and reliable. The integration of high temperature steam electrolysis for ironmaking has several additional advantages. First, this technology is characterized by extremely high efficiencies if steam is available. Even low energy waste heat, which is sufficiently available in steelmaking plants, can be used for steam generation. Second, the by-product oxygen can be effectively utilized for enrichment of the hot blast. And third, solid oxide technology enables also the reduction of CO_2 to CO, the main reducing agent of today's ironmaking. Based on this technology, various process applications including closed loop gas circulation are imaginable.

PAUL WURTH has selected SUNFIRE's solid oxide technology as a promising solution for the production of green hydrogen, which has already been successfully tested in the context of the GrInHy (Green Industrial Hydrogen) project integrating the electrolysis in the European steel plants. Other alternative electrolysis technologies demand around 30-40% more electrical power for the same output of hydrogen.

Conclusion

European steel industry today has both the challenges as well as opportunities to improve their process and operating practices in order to effectively respond to the global climate change. The opportunities rely on the expected global shift to a clean and green economy in the future. The challenge is to implement incremental CO_2 saving technologies in the BF plant along with ensuring the cost competitiveness and in parallel gearing up for complete H_2 based steel making process to meet the final CO_2 reduction targets. This can only be achieved, if steel makers and policy makers both work hand in hand to create a viable economic environment for the steel producers in Europe.

PAUL WURTH is employing intensive research and development work in order to ensure that the BF-BOF route will be compatible with future environmental and economic environment. Moreover, PAUL WURTH is also strongly engaged in the substitution of fossil energy carriers with H_2 in the steel making process. This includes integration of hydrogen in the BF and the complete hydrogen based steelmaking.

In the present paper PAUL WURTH has presented different technologies for the classical blast furnace route in view of incremental CO_2 emission abatement, which will be possible to implement according to the future political targets as well as economic framework. Many of these technologies are readily available, others are in ongoing development. In the very short term smaller CO_2 savings from the BF route can be achieved simply by retrofitting the steel plants with existing technologies.

Abbreviations

BF	Blast furnace
RAFT	Raceway adiabatic flame temperature
PCI	Pulverized coal injection
NG	Natural gas
BFG	Blast furnace gas
COG	Coke oven gas
DRI	Direct reduced iron
HBI	Hot briquetted iron

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