SIMETAL[CIS] COREX / FINEX PREPARED FOR PRESENT AND FUTURE IRON MAKING CHALLENGES[1]

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Abstract

Steel work operators face a plenty of challenges in a dynamic market, where even short and mid term fluctuations show their impact in a dramatic way. Hence unfortunately, long term considerations seem to be neglected, although especially in the raw material sector radical changes are inevitable. Resource depletion is not leading to a price increase only; non renewable raw materials along with a rising demand create a supply bottleneck. This is expected for coking coal, as well as for natural gas, where the industry is forced to give off more of its shares for public demands like power generation, fertilizer production and/or heating purposes. On the other hand, environmental care, which is by far not only the reduction of greenhouse gas emissions, becomes an important economical driving factor as well. More enforced environmental restrictions by law causes operators to revise their production routes to sort out processes which are not complying with these regulations. Answers to these scenarios give the established COREX technology and the new COREX "Low Export Gas" and the COREX/FINEX "(L)ow (R)educed (I)ron" concepts. These concepts lead to significant fuel savings for hot metal production, either by direct savings in the COREX/FINEX processes or indirectly by supporting the traditional blast furnace route. By fulfilling the criteria, utilization of low cost / high available raw materials, overall fuel savings even for the blast furnace and the impressive ecological advantages, once again the COREX/FINEX technology approve themselves as recommendable alternatives to the blast furnace and/or a reasonable expansion/substitution of existing production routes.

Key words: Corex; Finex; Smelting reduction; Environment; Blast furnace.

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Process description

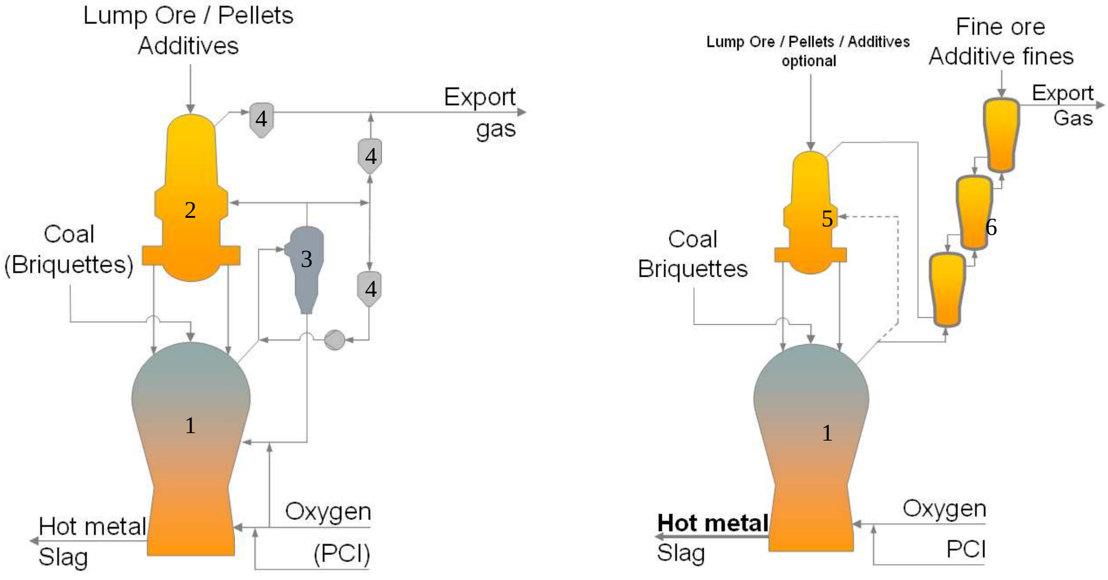
COREX and FINEX are commercially proven smelting reduction processes that allow for cost-efficient and environmental friendly production of hot metal directly from iron ore and non-coking coal. The process was developed to industrial maturity by SIEMENS VAI and is the only alternative to the blast furnace route consisting of sinter plant coke oven and blast furnace.
It distinguishes itself from the blast furnace by:

- Direct use of non-coking coal and a minimum of coke as reducing agent and energy source for melting purposes
- Direct use of iron ore in form of lump ore, pellets sinter and, especially for FINEX, fine ore

In the COREX process all metallurgical work is carried out in two separate process reactors – the reduction shaft and the melter gasifier (
Figure 1, left). Iron ore (lump ore, pellets, sinter or a mixture thereof) is charged into the reduction shaft where they are reduced to direct reduced iron (DRI) by the reducing gas in counter flow. Discharge screws convey the DRI into the melter gasifier, where final reduction and melting takes place in addition to all other metallurgical reactions. Hot metal and slag tapping are done as in conventional blast furnace practice. For the FINEX technology, the reduction shaft is replaced by a fluidized bed reactor stage (
Figure 1, right), where fine ore is directly used. Viewing the process from the coal route perspective, coal is directly charged into the melter gasifier. Coal gasification by oxygen injection results in the generation of a highly efficient reducing gas which is blown in the reduction shaft or the fluidized bed reactor stage as described above.

COREX procces

FINEX process
(simplified, without gas cleaning circuit)



[1] Melter Gasifier; [2] Reduction Shaft; [3] Hot gas cyclone; [4] Process gas scrubbers; [5] HCI bin; [6] Fluidized bed reactor

Figure 1: COREX / FINEX process flowsheets.

COREX / FINEX vs. Blast Furnace Route

Figure 2 compares the COREX/FINEX processes with conventional blast-furnace iron making. In the blast-furnace process, blended iron-ore fines are agglomerated at a sinter plant, and coking coal is processed at coke-ovens in preparation for use in the blast furnace. The main shortcomings of this conventional process are high raw-material costs and considerable pollutant emissions from the pre-processing plants.

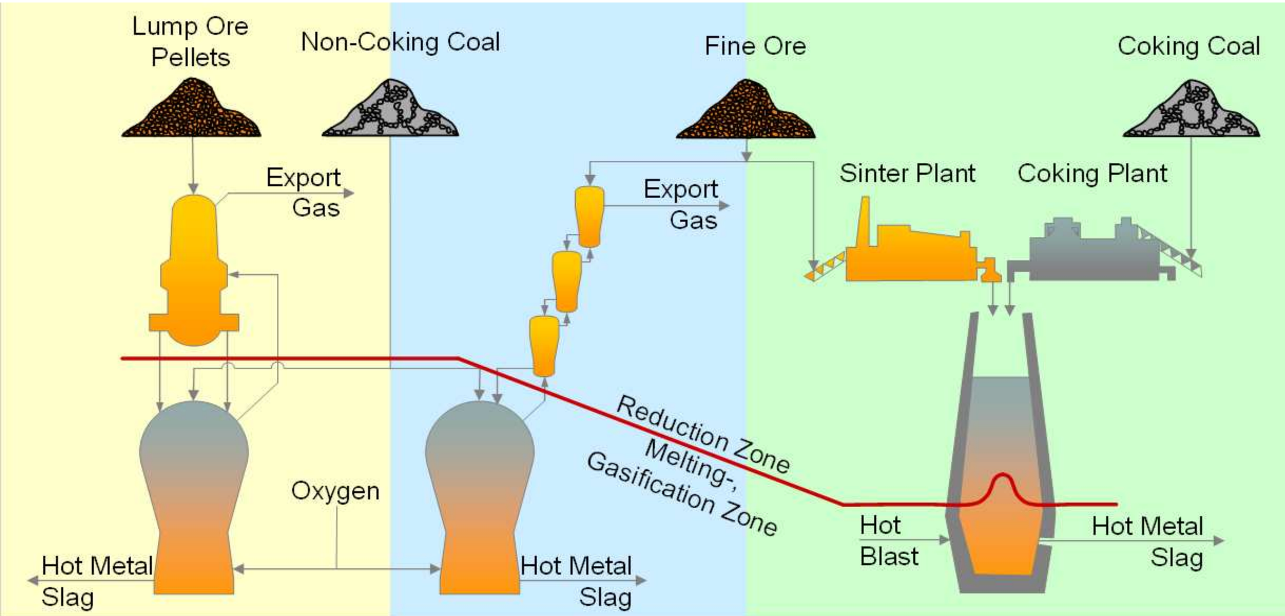


Figure 2: COREX / FINEX - Blast Furnace process comparison.

Current status of operating plants

COREX C-3000 BaoSteel / China

Figure 3: COREX C-3000 BaoSteel module 1.

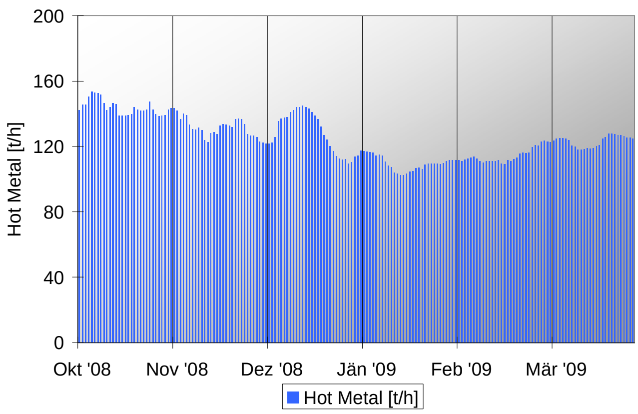


Figure 4: Production figures Baosteel (10 days average).

Shanghai Baoshan Iron & Steel Co., Ltd., Medium & Heavy Plate Branch / China, the largest steel producers in china operating a COREX C-3000 plant with an annual output of 1.5 million tons hot metal, witch was started up in November 2007. A second plant is already under construction and will be put in operation in 2011. Due to the financial crisis, the output of the plant was decreased continuously, throughout the month of January melting rate was restricted to even 100-120 [t/h]. End of March, test runs started with a Pulverized Coal Injection system, an important step towards fuel savings as it has been proven at the FINEX plant in Korea. With a hopefully increasing future steel demand, the plant will be able to demonstrate its performance.

COREX C-2000 Jindal / India

Figure 6: 2 x COREX C-2000 Jindal (module 1 / module 2).

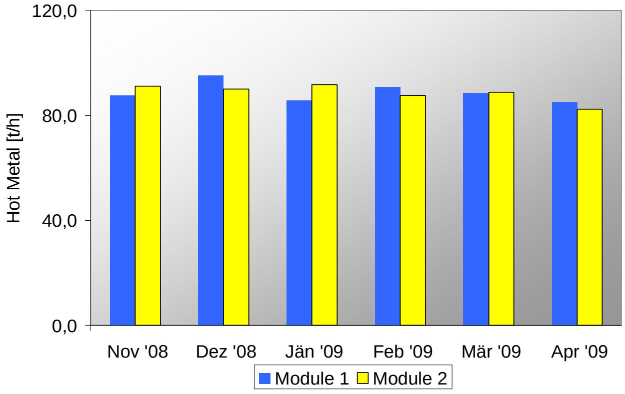


Figure 5: Monthly production figures Jindal (module 1 & 2).

At Jindal South West Steel Ltd more than 70% of the plant wastes, such as COREX and BF sludge, limestone/dolomite fines, LD slag, etc. are recycled into the two COREX modules either directly or indirectly through the pellet/sinter plants. The synergy of COREX and blast furnace has helped JSW steel to maximize the utilization of solid waste and thereby reduced the cost of hot metal. In addition, COREX export gas is used as back-up in blast furnace stoves, boilers, and in the sinter and pellet plant. Figure 6 shows the average monthly melting rate of each of the two COREX modules during a 6 months period. Jindal is in the fortunate position to keep production high due to the ongoing demand for steel products in India.

COREX C-2000 ArcelorMittal / South Africa

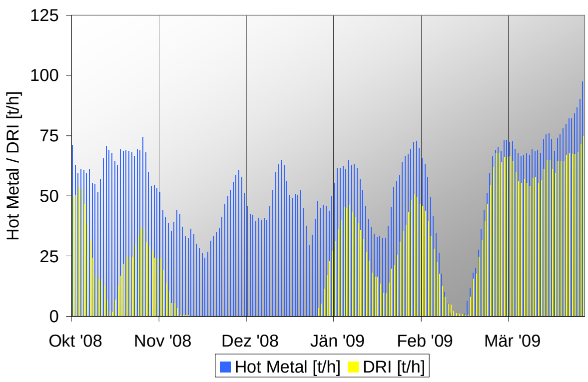


Figure 7: Production figures Saldanha (10 days average).

Figure 8: COREX C-2000 DR combination Saldanha.

ArcelorMittal South Africa (Saldanha) is operating a COREX C-2000 plant with a downstream DR plant for the production of DRI. The capacity of the hot metal production is 650.000 tons and the DRI production 800.000 tons a year.
After relining of the plant in 2008, the financial crisis hit the steelworks. A complete shut down of the plant would have been the worst case scenario especially for the relined iron making plant. Drastically countermeasures took place to keep the plant in operation: A stop and go operation to keep the output as low as possible started in November 2008. As its shown in Figure 7, the hot metal production dropped down to ~25 [t/h], the DRI production was stopped completely. This kind of action is unthinkable for a blast furnace. After some extensive maintenance stops in February, the plant is on the way to its typical performance, the financial situation improved and even allows the production of DRI.

FINEX 1.5M Posco / Rep. of Korea

A 1.5 million tons per year FINEX commercial plant has been operating at Posco's Pohang Works since April 2007. The start-up operation was carried out smoothly, and improved gradually over time. Recently, the normal operational performance has been achieved, satisfying target values of production rate, coal consumption, plant availability, and hot-metal quality. Low grade ore with high alumina content resulting in a high Al_2O_3 content in the slag which is restricted in the blast furnace, is used. Table 1 outlines the performance data of a FINEX plant and a blast furnace, operated at the same location at Posco's Pohang Works. A milestone to reduce investment cost was reached with a successful 3-reactor test in October 2008. It has been proven, that the same operation results, product qualities and plant availabilities could be reached along with significant reduced operational cost.

Figure 9: FINEX 1.5M Posco.

Table 1: Posco's FINEX 1.5M vs. Posco's BF4

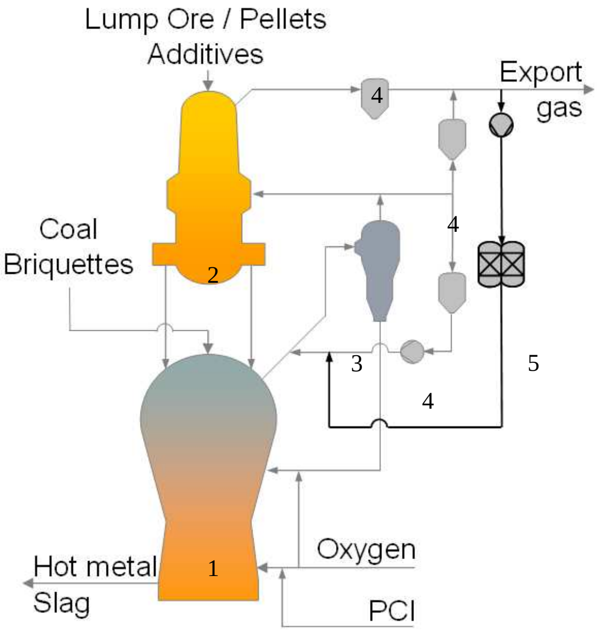
		Pohang BF4	FINEX 1.5M
Production [t/d]		8851	4305
Plant Availability [%]		98	95
Hot metal	T [°C]	1514	1530
	C [%]	4.5	4.5
	Si [%]	0.53	0.85
	S [%]	0.027	0.027
Slag	B_2	1.21	1.21
	Al_2O_3 [%]	15.62	18.03
	[kg/t HM]	298	271

Gas recycling

The conventional Corex process already operates resource preserving. The gas production, which is based on pure oxygen, leads to a high-quality export gas, best applicable for power generation and other purposes, e.g. heating or further chemical processing.
On the other hand, a valuable second product of this amount is not always an adequate solution. So the focus of process improvement is laid on the technologies intrinsic determination of efficient hot metal production.

COREX “Low Export Gas”

To recycle the export gas – after appropriate conditioning – for metallurgical work in the process, describes in simple words the principle of the Corex “Low Export Gas” alternative. Figure 10 shows the flow sheet of a partial export gas recirculation: in an adsorption system[1] the recycled gas is liberated from CO_2, the CO and H_2 enriched gas is reused for iron ore reduction.



[1] Melter gasifier [2] Reduction shaft
[3] Hot gas cyclone [4] Process gas scrubbers
[5] Gas recycling system

Figure 10: COREX recycling layout

Less generator gas from the melter gasifier is necessary to supply a sufficient amount of reducing potential, which is directly reflected in a lower fuel and oxygen consumption.
Table 2 shows the different consumption figures of the “Low Export Gas” concept compared to the standard Corex process:

		Standard	Recycle
Fuel	[kg]	940	770
Iron carrier	[kg]	1,500	1,500
Additives	[kg]	265	185
Oxygen	$[m^3]_{STP}$	520	455

Table 2: Specific consumption figures per ton hot metal

The - in smaller quantities and with lower heating value - resulting export gas can be used as well for power generation. Table 3 compares the produced “by-products” amount and the heating value of the export gas:

		Standard	Recycle
Export gas	$[m^3]_{STP}$	1,650	1410
Slag	[kg]	340	265
Export gas energy	[GJ]	13.5	10.2

Table 3: Specific “by-product” figures per ton hot metal

It can be seen, that the slag production goes down by more then 20% along with the decreased coal consumption, which is a further reduction of energy loss caused by the sensible heat of the slag and lowered additive consumption.
With an implemented recycling circuit, it’s open to the operator to adjust the system according to its own requirements, in the range from minimum coal consumption to maximized export gas generation, to react accordingly to the steel works demand.
The reduced export gas amount leads to a smaller investment for a downstream power plant as well, in the case, a large amount of electricity is not required for export “over the fence”.
Figure 11 illustrates the thermal and electrical energy flows considering the power consumptions of the COREX plant and the air separation unit based on 1 million tons

[1] a PSA or VPSA plant

of hot metal a year. The degree of efficiency of the fed combined cycle power plant is assumed to be h = 0.46.

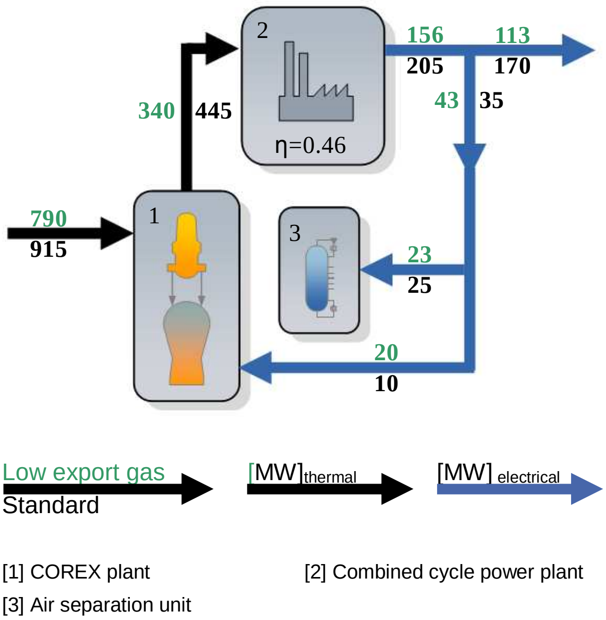


Figure 11: Export gas conversion into electricity

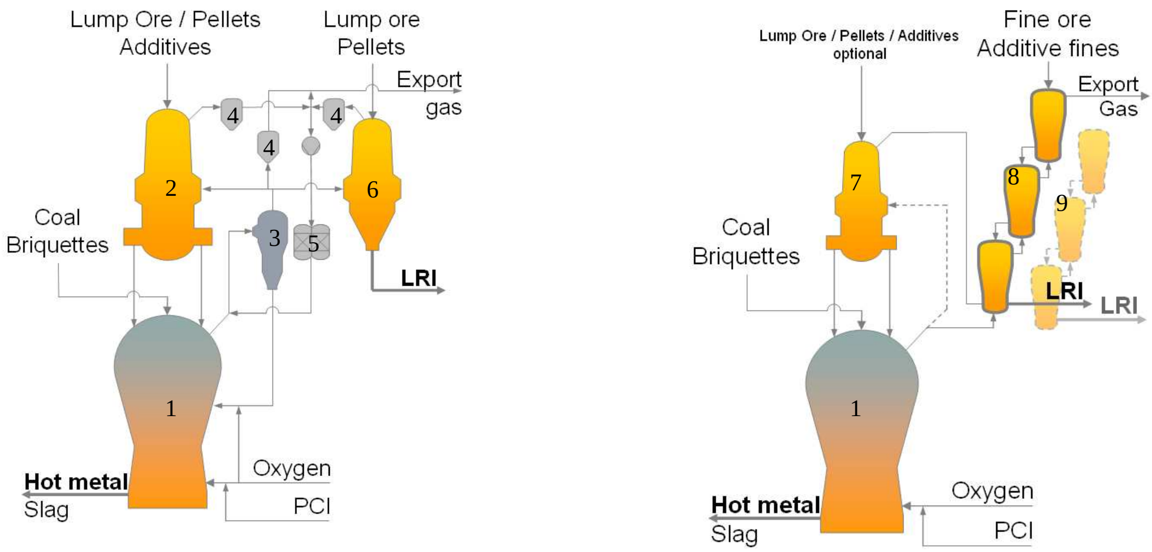
The difference in the thermal energy supplied to the system by the coal is ~125[MW]$_{th}$. Due to the higher efficiency of the recycle alternative, the difference in the thermal energy leaving the COREX process is reduced to ~105[MW]$_{th}$. The higher energy demand of the recycling circuit is not completely compensated by energy savings of the reduced oxygen production in the air separation unit, but the overall difference in produced electricity is ~57 [MW]$_{el}$.

LRI Concepts

“Low Reduced Iron” (LRI) is a pre-reduced material (met. ~50%) generated with the COREX/FINEX technologies in addition to hot metal. For a best possible incorporation of the COREX/FINEX technology into existing steel plants it is necessary to provide advantages for existing blast furnace routes. The process development of the COREX/FINEX LRI concepts aims in that direction. With the usage of LRI as iron carrier, the coke consumption is reduced and/or melting rate is increased which depends on the operation of the blast furnace without charging LRI. The specific portion of coke as reducing agent decreases, meanwhile the specific sinter, lump ore and/or pellet portion are also decreased as they are substituted by LRI. The blast furnace gains all advantages from the COREX/FINEX technology, which completely gets along without sinter and a minimum of coke. Beside the economical, the ecological advantages as well find its way to blast furnace hot metal production by the LRI concepts. For these reasons the COREX/FINEX LRI production is of high interest for brownfield projects, because of its ability to support existing blast furnace routes.

COREX / FINEX LRI

A recycle gas circuit combined with an additional “LRI” shaft is used for increased gas utilization. Contrary to the well-known Saldanha concept, where direct reduced iron (DRI) with a metallization of >90% is produced for downstream EAF processing, low reduced iron is directly used as pre-reduced iron carrier in the blast furnace as substitute for sinter, lump ore, or pellets. Figure 12 shows the process flow sheet of the COREX LRI concept. The FINEX process already consists of a recycling circuit, to maintain a sufficient fluidization velocity in the fluidized bed reactors. The expansion for LRI production can be achieved either by an up sc aling of the fluidized bed reactors or by the installation of a 2nd reactor stage (see Figure 12), which is operated parallel to the 1st reactor stage. A part of the produced HCI is further processed in a melter gasifier, the other part is discharged as LRI for blast furnace supply.



[1] Melter gasifier	[2] Reduction shaft	[3] Hot gas cyclone
[4] Process gas scrubbers	[5] Gas recycling system	[6] LRI shaft
[7] HBI bin	[8] Fluidized bed reactor stage	[9] 2nd reactor stage

Figure 12: COREX / FINEX LRI concepts

Blast furnace benefit

COREX and FINEX are excellent technologies for the production of pre-reduced iron ore for a further application in the blast furnace. The results of the impact of pre-reduced materials show, that a significant coal/coke saving or an increase in productivity is the result of the substitution of traditional blast furnace iron carrier with HBI/LRI.

Table 4 and Figure 13 show the impact of HBI usage in the blast furnace 1.

Charging of 100 [kg HBI/t HM]	Coke savings	PCI savings
Coke [kg/t HM]	-29.3	
Pulverized Coal [kg/t HM]		-34.4
Productivity [%]	+6.6	+3.8

Table 4: Effects of HBI charging

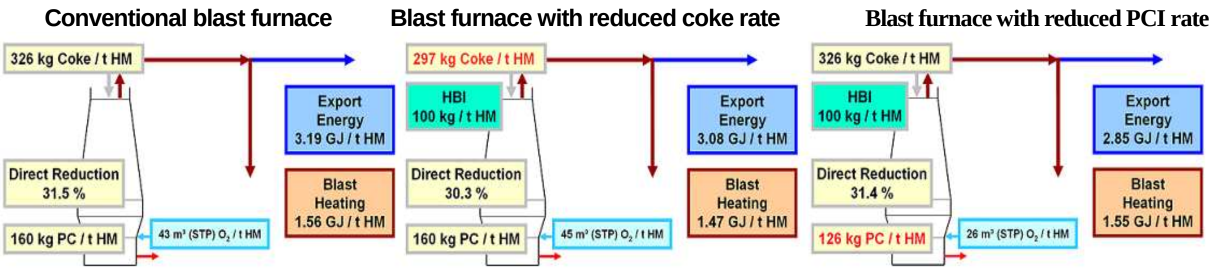


Figure 13: Impact of HBI usage in the blast furnace

Environmental aspects

Life Cycle Assessment

Life Cycle Assessment, LCA, is getting an internationally acknowledged tool to judge environmental impacts of the steel industry. In close cooperation with three universities – Technical University of Berlin (Germany), University of Mining and Metallurgy (Leoben, Austria) and Technical University of Denmark (Copenhagen) – an LCA study was conducted in 2007 and 2008 comparing the environmental impact of blast furnace route, COREX and FINEX using the environmental software tool "GaBi" for evaluation. Each step in the hot-metal production process, including the mining of iron ore and coal, the transportation to the plant site and the individual production steps were modeled and analyzed. All by-products and their subsequent utilization were also taken into account.

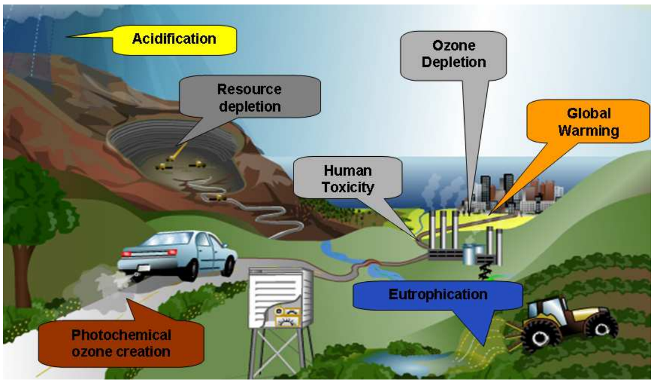


Figure 14: Environmental impact categories

Five key impact categories were identified in this study which considered most of the interfaces between the environment and the production process as a whole. The five categories are Acidification Potential, Abiotic Resource Depletion Potential, Global Warming Potential, Photochemical Ozone Creation Potential and Eutrophication Potential, as shown in Figure 14. The Acidification Potential (AP) provides an overview of the acidic components that are released to the environment. The Abiotic Resource Depletion Potential (ADP) considers natural resources. Processes are more sustainable if they are based on the use of coal, which is abundantly available worldwide, instead of non-coking coal, where resources are clearly limited.
Global Warming Potential (GWP): One of the most frequently discussed environmental topics today is global warming, which most experts believe is caused by an increase of so-called greenhouse gases in the atmosphere. These gases, including water vapor, raise the atmospheric temperature by absorbing infrared radiation reflected from the surface of the earth. Photochemical Ozone Creation Potential (POCP) describes the formation of ozone (O_3) in the presence of NO_x, hydrocarbons and sunlight (summer smog). Another important environmental impact factor is the Eutrophication Potential (EP), which determines the degree of over-fertilization. The relative importance and magnitude of the above-described impact

categories were evaluated with the CML normalization method (Centrum voor Milieuwetenschappen Leiden*, NL).

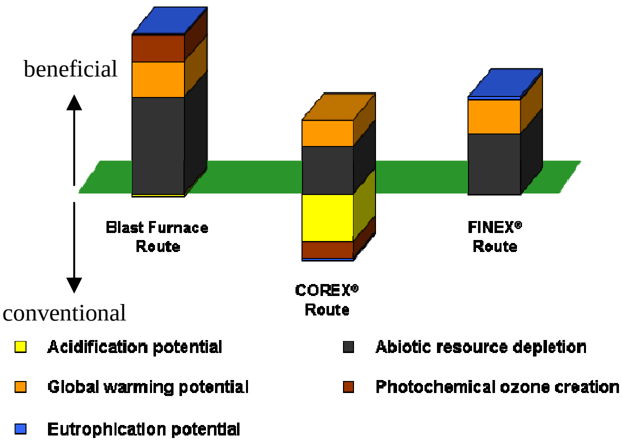


Figure 15: LCA results

Specific customer-relevant parameters and energy sources, have an influence on the overall picture. Different electricity mixes (country-specific ratio of hydroelectric-, atomic-, wind- or coal-based power generation) were also taken into consideration. F.e. the SO_2 – burden of electricity, which is generated from COREX/FINEX Export gas will be much lower than the SO_2 - burden of electricity generated by a coal based power plant. Therefore the credit from the COREX gas leads to an even positive impact on the environment, as illustrated in Figure 15. The results of an independent life-cycle assessment of the hot-metal production processes have shown that the COREX and FINEX processes are environmentally more compatible than the conventional blast furnace production route, especially at sites where coal is used as an energy source to generate electricity.

Conclusion

Taylor made hot metal production with a special focus on resource saving and an efficient implementation into existing steel works are the key features of the new COREX/FINEX concepts. The ecological and economical advantages of COREX/FINEX are beneficial for existing production routes as well as for new ones. During the past years, market conditions and "external" factors have also changed in favor of COREX/FINEX technology, e.g. mandatory environmental legislation, increased costs for metallurgical coal and an increased energy price. An answer to these challenges are the COREX "Low Export Gas" and the COREX/FINEX LRI concepts. Developments and optimization of COREX/FINEX are still underway and major additional economical and technological improvements are yet anticipated.

Outlook

While fuel consumptions for hot metal production is reaching its lower limits and gas utilization for reduction work is optimized continuously. Resource preservation and environmental care are one of the "hot potatoes" steel work operators have to handle in near future. The COREX/FINEX technologies already show their high potential on the way to an economical, ecological and responsible part in the steel making chain.

References

1 Paper of P. Schmöle and HB. Lüngen in Stahl und Eisen 127 (2007)