

FINEX® - AN OLD VISION OF THE IRON AND STEEL INDUSTRY BECOMES REALITY*

Shibu John¹
Christian Boehm²
Wolfgang Sterrer³
Norbert Rein⁴
Yi Sang-ho⁵
Shin Sungkee⁶

Abstract

Rising energy demand and steadily decreasing quality of raw materials due to the global resource depletion are great challenges to the steel production today. The FINEX® Process has been developed jointly by POSCO, Korea and PRIMETALS Technologies Austria, to provide the iron making sector with the capability to lower hot metal production costs, environmental pollutions and to increase the flexibility in terms of operation and the choice of raw materials. FINEX® is a new technology combining a gas-based reduction in a series of fluidized bed reactors and a reduction smelting in a melter gasifier. Commenced in April 2007, the first 1.5Mtpa commercial plant has demonstrated the competitiveness as an alternative iron making route. Another 2.0 Mtpa, third generation FINEX® (3G) plant was recently installed at POSCO, Pohang Works and has been operating satisfactorily since its blow-in in January 2014. Based on the well-proven plant concept, new process features, the highly competitive production costs and environmental advantages, the FINEX® Process can be considered as a competitive alternative to the conventional blast furnace iron making route.

Keywords: FINEX®; FINEX® export gas utilization; Hot metal; CO₂ mitigation.

¹ Head Direct and Smelting Reduction, Primetals Technologies Austria GmbH, Turmstrasse 44, 4031 Linz , Austria.

² Head of Sales, Primetals Technologies Austria GmbH, Turmstrasse 44, 4031 Linz , Austria.

³ Head of Technology Department Smelting Reduction, Primetals Technologies Austria GmbH, Turmstrasse 44, 4031 Linz , Austria.

⁴ Senior Expert Direct and Smelting Reduction, Primetals Technologies Austria GmbH, Turmstrasse 44, 4031 Linz , Austria.

⁵ Senior Vice President, Head of FINEX® R&D Project Department, POSCO Ltd., Seoul, Korea.

⁶ Sr. Manager, Steel Investment & Technology Planning Department, POSCO Ltd., Seoul, Korea.

1 INTRODUCTION

1.1 Process Description

In the FINEX® Process the iron production is carried out in two separate Process steps. In a series of fluidized bed reactors, fine-grained iron oxides are reduced to direct-reduced iron, compacted and then transported to a melter gasifier. Coal and coal briquettes charged to the melter gasifier are gasified, providing the necessary energy for melting in addition to the reduction gas.

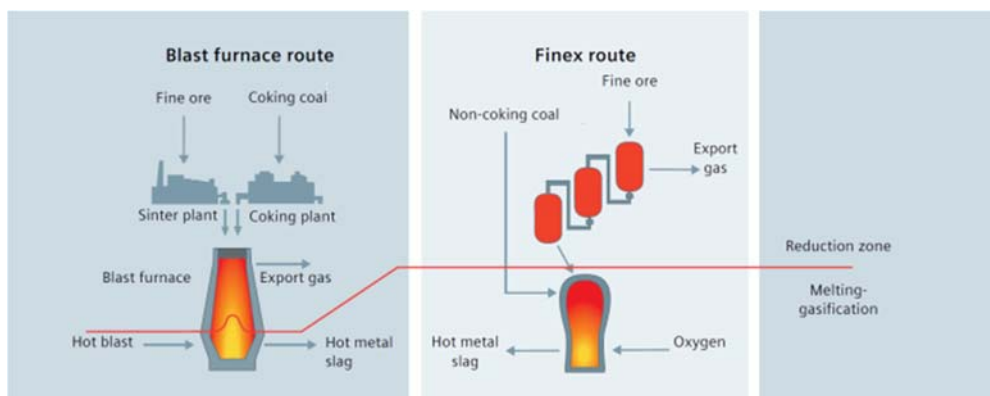
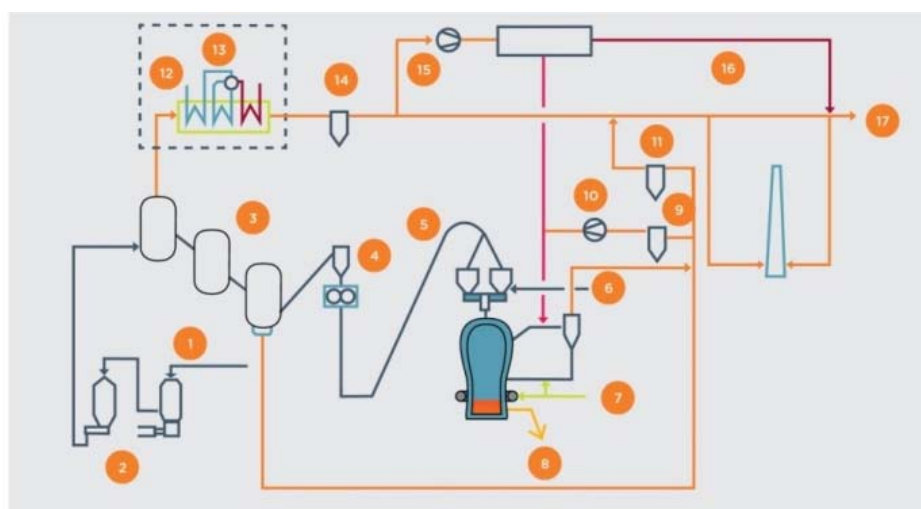


Figure 1: Process comparison FINEX® / BF route

2 BASIC PRINCIPLE



The typical FINEX® Process flow sheet

- | | | |
|---|---|--|
| 1 Ore, additive drier | 7 Oxygen, PCI (Pulverised coal injection) | 13 Waste HRSG (Heat recovery steam generation) |
| 2 Pneumatic ore transport | 8 Hot metal, slag | 14 TG (Top gas) scrubber |
| 3 Fluidized bed | 9 CG (Cooling gas) scrubber | 15 RGC (Recycle gas compressor) |
| 4 HCl (Hot compacted iron) plant | 10 CGC (Cooling gas compressor) | 16 Tail gas |
| 5 HCl (Hot compacted iron) Hot conveyor | 11 EG (Excess gas) scrubber | 17 Export gas to power plant and raw material drying |
| 6 Coal briquettes | 12 Steam | |

Figure 2: FINEX® Process flow sheet

Fine ore and additives (limestone and dolomite) are dried and then charged to a 3 or 4 stage fluidized bed system where the iron ores are progressively reduced in counter current flow with the reducing gas to fine DRI and the fine additives are partly calcined. The reduction degree of the DRI fines is in the range of 60 to 85%.

Subsequently the fine DRI is compacted to HCl (hot compacted iron) and charged continuously to the melter gasifier. By means of gravity, the hot HCl falls through the dome zone into the char bed, is heated up, finally reduced by ascending reduction gas and melted down. The liquid hot metal and slag are collected at the melter gasifier and tapped frequently similar to blast furnace practices.

Coal (lumpy and/or briquetted fine/undersize coal) is charged from the top of the melter gasifier, dried and degassed in the upper char bed area and finally the degassed coal (char) is gasified with pure oxygen which is blown in at the tuyere zone of the melter gasifier bed. The gasification supplies the energy required for the metallurgical reactions and for the melting of HCl and coal ash to hot metal and slag. Pulverized coal injection (PCI) system is provided to inject fine coal via the oxygen tuyeres.

The generator gas, which is leaving the melter gasifier, consists mainly of CO and H₂ at a temperature level of ~1.000 °C. Prior using it as reducing gas in the fluidized bed, its temperature is adjusted by adding cold gas from a cooling gas system and/or cold product gas from a PSA (pressure swing adsorption) plant. Subsequently it is de-dusted in hot gas cyclones. The dust separated in the cyclones is recycled to the melter gasifier by means of dust burners.

The conditioned reducing gas is then supplied to the fluidized bed system for indirect reduction of the iron oxides. The used reducing gas leaving the fluidized bed reactors can be partly recycled. For that purpose the recycle gas is compressed and CO₂ is removed in a pressure swing adsorption (PSA) plant. As a second valuable product FINEX[®] provides an export gas with a medium calorific value of 5,500 – 6,250 kJ/m³ STP which is typically supplied to the gas net of the steel works.

The export gas can be used as a fuel for energy production, heating purposes, production of chemical products/synthesis gas or production of additional DRI/HBI etc.

A typical analysis of FINEX[®] export gas is indicated in the following table:

Components	Export gas
CO	28-32 %
H ₂	8-12 %
CO ₂	44-48 %
H ₂ O	3-4 %
CH ₄	1-2 %
N ₂ /Ar	4-10 %
Dust	< 5 mg/m ³ (STP)
H ₂ S	< 100 ppmv
Calorific value	5500 - 6250 kJ/m ³ (STP)

Table 1: Typical FINEX[®] export gas quality

3 MATERIAL AND METHODS

3.1 Development and Industrial Application of FINEX[®]

In December 1992, POSCO and PRIMETALS signed a cooperation agreement for the joint development of the FINEX[®] Process. Following initial laboratory, bench scale and pilot-plant tests, in 2002 the existing COREX[®] plant was converted into the

FINEX[®] F-0.6M Demonstration Plant with a nominal capacity of 0.6 million t/a hot metal, which commenced operation in May 2003. In July 2014, the operation was stopped and it is under investigation to relocate the plant to India.

On the basis of the successful results and following optimization of equipment and Process parameters, POSCO decided to install the industrial FINEX[®] F-1.5M Plant (1.5 million t/a nominal production capacity). POSCO broke the ground to build the first commercial FINEX[®] F-1.5M Plant in August 2004. The plant has commenced operation in April 2007.

Based on the successful results of the FINEX[®] F-1.5M Plant, POSCO and PRIMETALS decided to develop the FINEX[®] F-2.0M Plant with an annual hot metal capacity of 2 million t/a. In 2011 POSCO started to build the first FINEX[®] F-2.0M and the plant has been successfully put into operation in January 2014 and produced approx. 1.5 million tons of hot metal in the first 11 months.



Figure 3: FINEX[®] F-0.6M Demonstration Plant



Figure 4: FINEX[®] F-1.5M Plant



Figure 5: FINEX[®] F-2.5M Plant

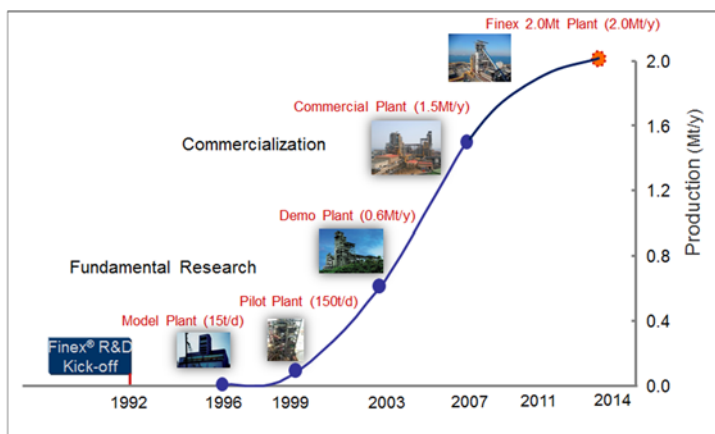


Figure 6: Scale up history of FINEX®

3.2 Operational Results from the FINEX® F-2.0M Plant

The design of the third generation FINEX® F-2.0M plant is characterized by a simplified plant concept resulting in decreased construction weights compared to the F-1.5M concept. Beyond others, following major design features distinguish this development:

- Pneumatic ore charging to the fluidized bed reactors incl. a 3-stage fluidized bed reactor system resulting in a decreased building height of more than 30%
- Simplified system configuration in the hot compacting system and implementation of dry de-dusting equipment
- Elimination of HCl bin and related top gas system in the melter gasifier tower
- Installation of a centre charging system for hot HCl and coal, allowing for homogeneous charging of feed materials to the melter gasifier. The distribution on the char bed surface is realized via a dynamic gimbal distributor.

Implementing these improvements to the Process reduced the overall construction weight of the FINEX® F-2.0M plant by approx. 9% and required no larger space in the plant layout.

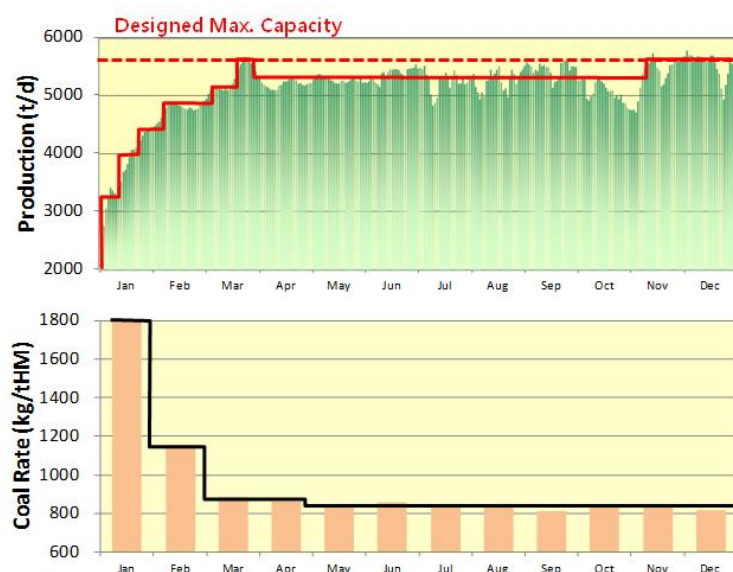


Figure 7: Production and coal rate of F-2.0M plant

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After start-up in January 2014, operation optimization and facility stabilization, the productivity of the F-2.0M plant achieved its target value of 5760 t/d in April 2014. Since then operation targets are achieved and operational optimization is under progress to further optimize coal consumption.

Due to improvements in equipment and operational skills, the target availability of >95% could be achieved in the first months of operation.

Typical consumption figures are:

Coal	819 kg/t _{HM} (dry)
Ore	1,624 kg/t _{HM}
Additives	250 kg/t _{HM}
Oxygen	485 m ³ (STP)/t _{HM}
Nitrogen	370 m ³ (STP)/t _{HM}
Make up water	1 m ³ /t _{HM}
Electric energy	214 kWh/t _{HM}
Export gas credit	9 GJ/t _{HM}

Table 2: FINEX[®] consumption rates ('14.12)

3.3 FINEX[®] Modules and Plant Configuration

Different sizes of FINEX[®] modules are available to meet specific requirements of the customers:

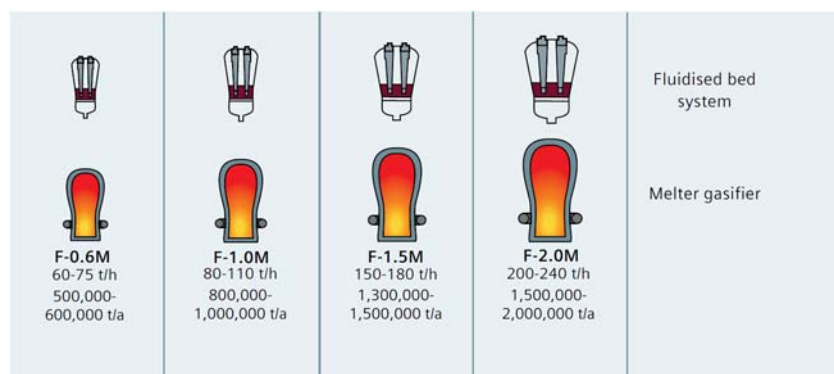


Figure 8: Available FINEX[®] module sizes

3.4 Utilization of the FINEX[®] Export Gas

The export gas is a mixture of the not recycled off gas, excess gas and the tail gas of the pressure swing adsorption (PSA) plant. Similar to the Corex[®] export gas, FINEX[®] export gas can be used to substitute natural gas, oil, coke and coal for numerous applications, including:

- Electrical power generation
- DRI production
- Heating purposes
- Steam generation
- Raw material drying
- Pelletizing plant
- Production of synthesis gas

Depending on the composition of coal and the decision whether gas recycling is applied or not, the amount and the composition of the export gas can vary within definite limits.

3.4.1 Great Potential for CO₂ Mitigation

The FINEX[®] Process also offers the possibility to generate high purity CO₂ to be further available for sequestration, oil recovery enhancement or other economical use. Based on the fact, that high purity oxygen in the melter gasifier is used to gasify coal, the export gas contains low amounts of nitrogen.

This fact allows to scrub out the CO₂ in high concentration from the recycling gas and to generate after further purification (CO₂ > 95%) high purity CO₂.

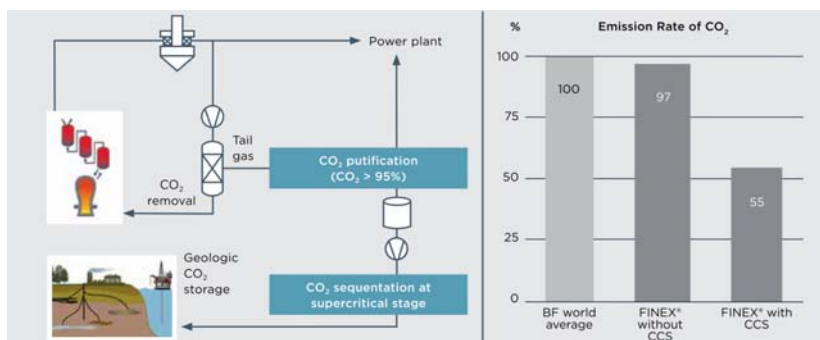


Figure 9: Great potential for further CO₂ mitigation

3.5 Environmental Considerations

In the FINEX[®] Process the gaseous emissions as well as the water emissions like dust, SO₂, NO_x, phenols, sulphides, ammonia are significantly lower than in a conventional blast furnace route. This is primarily based on the fact, that the FINEX[®] Process does not need any sintered ore and only little coke compared with a blast furnace. The sinter plant and the coke oven battery are the actual sources of emission in a conventional blast furnace route.

Thanks to the in-situ coking of the coal in the melter gasifier, a large portion of sulphur is captured in the slag, dramatically decreasing emissions of gaseous SO₂ or H₂S. Furthermore pure oxygen is used instead of the hot air blast, significantly reducing nitrogen emissions in the form of NO_x and providing the advantages already mentioned regarding dust emissions.

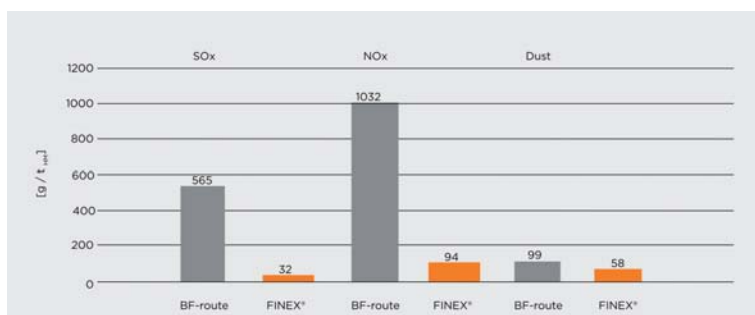


Figure 10: Emission comparison FINEX[®] / BF

3.6 Raw Material Flexibility

Typically a wide range of raw materials can be used in the FINEX[®] Process. However both, iron carrier and fuel materials have to meet certain requirements for optimum plant performance with regard to chemical composition and thermal strengths.

3.6.1 Fuel

The major criteria for an initial evaluation of coals or coal blends for the FINEX® Process are:

- Fix carbon content at a minimum of 55%
- Ash content up to 25%
- Volatile content lower than 35%
- Sulphur content lower than 1%

Additional to these qualities the coal must have a good thermal stability to ensure the formation of a stable char bed in the melter gasifier.

For the FINEX® Process either lump coals / coal briquettes or a mixture of lump coals and briquettes can be utilized.

The screened out undersize coal fraction can be utilized in different ways, but it is recommended to install an undersize coal briquetting plant and reuse the complete fraction at the FINEX® plant itself.

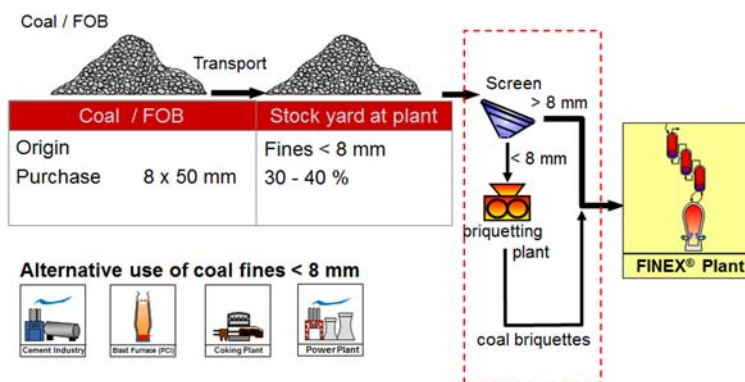


Figure 11: Utilization of coal undersize fraction / undersize coal briquetting plant

Integration of the coal briquetting technology increases the range of suitable coal blends for the FINEX® application. Utilization of 100% coal briquettes offers the possibility to mix different coal qualities for the generation of coal briquettes. There is a wider market for coal fines and therefore by purchasing different fine coal qualities raw material costs can be decreased and the coal briquettes be manufactured for optimum performance inside the FINEX® melter gasifier.

	V.M. (%)	Ash (%)	FSI	BF	FINEX®	
					F-06M	F-1.5M
Thermal coal	30-38	< 17	0-2		20%	10%
Semi-soft coking coal	28-34	< 10	1-6	40%	80%	80%
Hard coking coal	20-26	< 10	6-9	60%		10%
Semi-antracite	10-15	< 15	0-2			

Annotations: A double-headed arrow labeled 'China' connects the BF column for Semi-soft coking coal and Hard coking coal. A double-headed arrow labeled 'PCI' connects the F-06M and F-1.5M columns for Thermal coal. Vertical double-headed arrows labeled 'Coal briquettes' connect the F-06M and F-1.5M columns for Semi-soft coking coal and Hard coking coal.

Figure 12: Raw material coals utilized in FINEX®

By purchasing lower coal qualities for coal briquettes used in FINEX®, OPEX can be decreased compared to the blast furnace.

3.6.2 Oxide

In general, 100% of sinter feed fine ore is charged into the fluidized bed reactors. Up to 30% of pellet feed is also applicable. Brands and mix of iron ore are decided in

consideration of chemical and physical properties such as total Fe content, composition structure, grain size, etc.

In the same manner as of blast furnace Process, Fe content of iron ore determines the productivity. The mixing ratio should be decided by considering ore quality and the price together. Since higher alumina slag tapping is more tolerable in FINEX[®] than in blast furnace, high alumina content of iron ore is also allowable. Generally, there is no limitation in feeding material structure of hematite and goethite to fluidized bed reactors.

Generally following data shall be fulfilled by the iron ore to be charged to the fluidized bed system:

Criteria	Guideline Value	Remark
Chemical Analysis		
Fe content	min. 55% (up to local condition)	preferred: 60%
SiO ₂ + Al ₂ O ₃	max. 6%	limit is slag amount

Table 3: Required iron ore properties

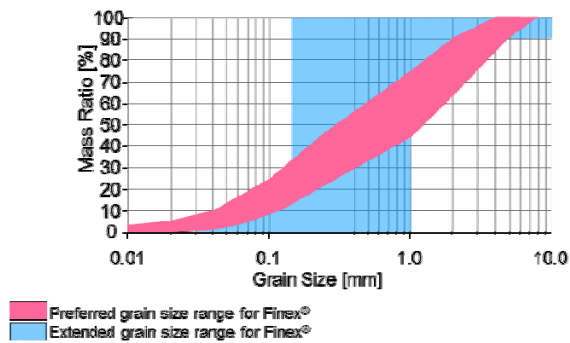


Figure 13: Typical feed size distribution of iron oxide fines

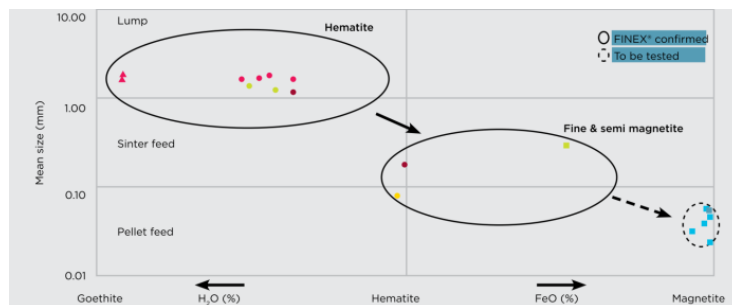


Figure 14: Flexibility of suitable ores for FINEX[®]

Based on the usage of different ore brands in the Finex plant, any hematite ore can be used regardless of brand, goethite, containing a high water of crystallisation, can also be used and low-price magnetite is applicable up to max. 30%.

4 RESULTS AND DISCUSSION

4.1 Economic Considerations

For an economic assessment with regard to hot metal production costs and the comparison of different technologies, it is essential to consider the overall plant configuration for iron and steel making. Following items underline the cost competitiveness of the FINEX[®] Process:

* Technical contribution to the 46^o Seminário de Redução de Minério de Ferro e Matérias-primas, to 17^o Simpósio Brasileiro de Minério de Ferro and to 4^o Simpósio Brasileiro de Aglomeração de Minério de Ferro, part of the ABM Week, September 26th-30th, 2016, Rio de Janeiro, RJ, Brazil.

Low CAPEX:

- Elimination of expensive coking and sintering plants
- Compact land use
- Lower construction volume
- Lower investment for integration facilities and utilities e.g. power and utilities distribution, road network etc.

Lower OPEX:

- No need for high ranking coal, sinter and pellets
- No need for blending raw materials

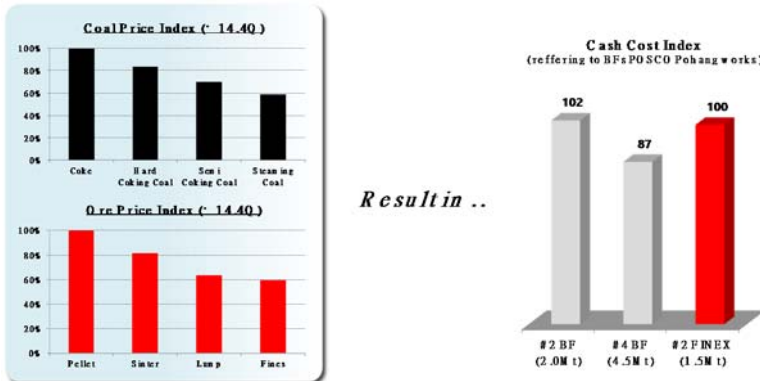
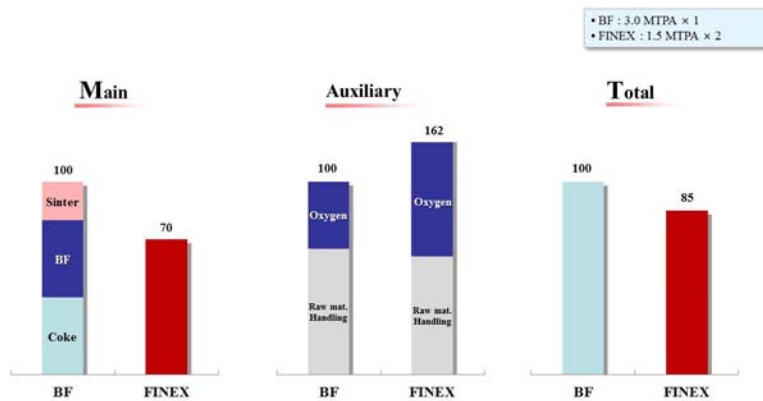


Figure 15: OPEX comparison FINEX® / BF (14.4Q)



※ Figures refer to POSCO's steel works in Korea. It may vary under the different local conditions.

Figure 16: CAPEX comparison FINEX® / BF

5 CONCLUSION

Adaptive iron making technologies become more and more important in a dynamic steel market, where future demands and boundary conditions change in a never seen frequent way. Prospective challenges are the ongoing changes in the raw material sector, the general fluctuation of energy costs and more stringent environmental laws.

The FINEX® Process already shows a high competitiveness compared to the blast furnace route. As further optimization of the FINEX® Process is still underway, major additional economic and technological improvements are yet anticipated.

With consideration to the highly flexible plant concepts, well proven components and systems, new Process features as well as the highly competitive production costs, POSCO and PRIMETALS are confident that the FINEX® Process will capture an increasing share of the hot-metal production worldwide.

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