FUTURE TRENDS IN IRONMAKING

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Abstract: The role of the blast furnace in steel production is discussed followed by the trends in blast furnace performance. The issues facing the blast furnace process are: external such as coke supply and internal such as limitations on coal injection and hearth life, as influenced by phenomena in the various furnace zones. The challenges to the blast furnace process include both alternative steel production routes such as the integrated DRI/scrap/EAF mode and also alternative hot metal processes. These DRI and alternative hot metal processes will be listed with comments as to their future success.

INTRODUCTION

The blast furnace today continues as the primary production method of hot metal in large-scale steel production. The blast furnace process has been the target of repeated attempts to replace it with various process options, including direct reduction and coke-free smelting reduction. While these new technologies are being adopted in appropriate niches, the blast furnace has responded to the challenge by being amenable to continuous improvement. I will review the role of the blast furnace, major developmental and improvement trends, and then list the current important issues in ironmaking. I will outline the challenges, including alternative processes, to be faced by the blast furnace to maintain its position as the primary hot metal production process. The material presented here is an update of earlier presentations (2-10)

ROLE OF THE BLAST FURNACE

There has been speculation about the demise of North American blast furnaces; in fact going back to the 1950’s when many direct reduction processes were being developed. It did not happen then and won’t happen now although the number of blast furnaces is decreasing. After 50 years of effort, North American (excluding Mexico) DRI production had been less than 2 MT/yr. while worldwide DRI production is about 75 MT/yr. With low cost natural gas now available in the USA DRI plants are now being built; the Nucor 2.5 MTPY DRI plant started up in Louisiana late last year while another 2 MTPY HBI plant is being built in Texas. However, on a global basis, world virgin iron unit production is over 1100 MT/yr. so nearly 95 % of virgin iron units are produced by the blast furnace. Some WSA data (MT/yr.) are follow:

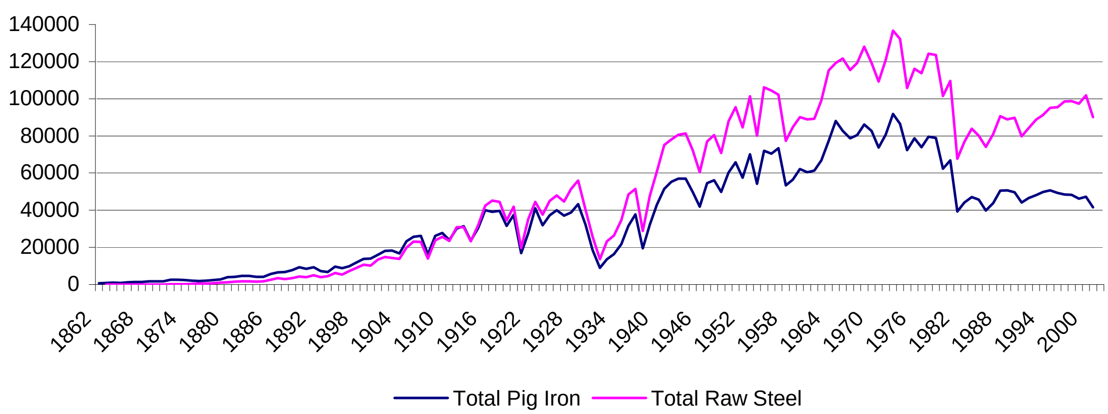
Region	2002 Pig Iron Production	2002 Crude Steel Production	2002 Pig Iron/ Crude Steel	2013 Pig Iron Production	2013 Crude Steel Production	2013 Pig Iron/ Crude Steel
EU	89.7	158.6	0.56	92.5	165.6	0.56
Other Europe	22.9	45.0	0.51	10.3	36.6	0.28
C.I.S.	77.9	99.9	0.78	82.0	108.7	0.75
North America	**52.9**	**123.6**	**0.43**	**41.4**	**119.2**	**0.35**
South America	33.4	40.9	0.82	30.0	46.0	0.65
Africa	7.1	15.7	0.45	5.9	15.7	0.38
Mid-East	2.2	11.9	0.18	2.0	25.9	0.08
Asia	308.9	381.9	0.81	897.3	1,059.1	0.85
China	**169.1**	**181.7**	**0.93**	**709.0**	**779.0**	**0.91**
Oceania	6.7	8.3	0.81	4.1	5.5	0.74
Totals	**603.9**	**885.8**	**0.68**	**1,164.6**	**1,582.5**	**0.73**
Total DRI	**45.1**			74.0		

Steel production has grown dramatically in China in the past decade with nearly all of this growth based on blast furnace ironmaking. As shown above, pig iron production increased by 461 MT from 2002 to 2011; such growth is phenomenal.

Year	**CHINA Pig Iron Production**	**Crude Steel Production**	**Iron Ore Imports**
1992	75.9	80.9	25.2
1997	115.1	108.9	55.1
2002	169.1	202.3	111.5
2004	251.8	272.4	208.1
2005	330.4	349.4	275.0
2006	407.5	424.2	326.0
2007	469.4	489.2	383.0
2008	471.1	500.5	443.6
2009	544.0	568.0	628.0
2010	581.0	627.0	618.6
2011	630.0	683.0	686.0
2012	657.9	716.5	745.4
2013	709.0	779.0	800.0e

The sharp growth in pig iron production has obviously led to construction of many new blast furnaces in China of all sizes from mini (450 M^3) to medium/large sized (2000 – 3200 M^3) and some very large (4300 M^3) furnaces. This growth in ironmaking has been fed mainly with imported iron ore, although China is also a major iron ore producer itself. Coal and coke demand have increased with one implication being a sharp drop in coke exports available to ironmakers elsewhere including those in North America and Europe.

The total number of BF's in the Western world has dropped by over 50% from the peak year of 1977 but BF productivity has more than doubled since 1977. Turning to North America, the growth in iron and steel production in Canada and Mexico has been steady while in the USA we can see in the figure below that steady growth (except for the Depression era) stopped with a major collapse in both iron (down to 40 MT/year) and steel production (down to < 80 MT/year) in the early 1980's. Since that time steel production has climbed to over 100 MT/year but iron production has remained in the 40 – 45 MT/year range. The lack of correlation between iron and steel production is due to the dramatic growth of the EAF sector in the USA. In Canada we have seen growth in both iron and steel production, with the predominance of the blast furnace route. In Mexico, growth has come predominantly from the "integrated" mini-mill route, production of DRI followed by EAF melting. We had expected that no new blast furnaces would be built in the developed world; we will see new blast furnaces in Brazil and India, as well as many in China. However, the steel industry resurgence in North America has led to construction of completely rebuilt or essentially new blast furnaces at existing sites (see below) while in Europe we have seen the new TKS Hamborn BF 8 being built.



In the USA the once predominant position of the fully integrated steel companies has been undermined by the following factors:

- The emergence of the electric furnace, scrap based mini-mills which have taken over production of virtually all long products, and are now encroaching upon flat products. EAF's have improved their production from less than 2 MT/yr. in 1940, to about 20 M tpy in the 1970's, to more than 50 MT/yr. by 2005
- Persistent competition from imports,
- Increased use of competitive materials.

In addition to the preceding external challenges, the blast furnace based companies have faced the following internal challenges:

- Environmental requirements have consumed large amounts of scarce capital, especially in the coke oven area
- Poor profitability has significantly constrained modernization spending

- High legacy costs: employee related expenses associated with downsizing

The consequences of all of the preceding upon the ironmaking sector has been:

- Reduction in hot metal demand, which has led to blast furnace shutdowns
- Reduction, and closures, of cokemaking facilities at certain locations
- Many sinter plant closures: environmental and excess pellet capacity issues
- Severely limited opportunities for modernization.

Within the past decade, the North American ironmaking sector has experienced an economic resurgence associated with the following positive factors: the reduction of legacy and overhead costs with restructuring, innovative labor agreements, major consolidation led by ArcelorMittal and USSteel, increased value of raw material assets such as pellet and coke plants, increased demand led by the China boom, favorable currency shifts, etc.

TRENDS IN BLAST FURNACE IRONMAKING

The major trends include facility modernization: building of larger furnaces and upgrading existing furnaces, very high productivity, major decreases in the use of fuel and reductants, extension of campaign life, and the improvements in raw materials which enabled the forgoing improvements.

Facility Modernization

The successful operation of blast furnaces with hearth diameters exceeding 13 meters and producing over 9000 MT/day has been noteworthy and in most countries medium to large sized furnaces are producing over 6000 MT/day. What may not be appreciated is the new construction or rebuilding of smaller and medium sized furnaces with modern equipment to achieve high productivity, low reductant rates, and extended campaign lives. This has been accomplished by either building small/medium sized furnaces where plant configurations do not favor large blast furnaces or by selectively upgrading older, smaller furnace. Examples of the latter are conspicuous in North America while examples of the former are seen in the Scandinavian region.

North American blast furnace operations - The scarcity of capital and the constraints of existing plant layouts have forced ironmakers to selectively upgrade many furnaces originally built in the 1950’s and 1960’s. These upgrades have been directed at intensified blast conditions (stove upgrades, installation of coal, gas injection, enhanced oxygen enrichment), improved cooling and refractory configurations, and retrofitted burden distribution equipment, instrumentation & data processing and cast floor improvements. The quality and consistency of raw materials has been improved: higher stability coke, fluxed pellets and selective use of prepared scrap and HBI.

Large blast furnace operations - the evolution towards larger furnaces has been nearly continuous in the history of ironmaking. This evolution appears to have reached its peak with the largest furnaces built in Japan, Germany and the CIS; The limited flexibility in adjusting to changes in hot metal demand and the increased raw material quality requirements, especially for coke, provide little economic incentive for the construction of furnaces any larger than the currently largest furnaces.

The resurgence in ironmaking in North America has been characterized by significant rebuilds of key furnaces: ArcelorMittal Indiana Harbor (ex-Inland) BF 7, USS Gary BF 14, ArcelorMittal Dofasco BF 2 and SeverstalNA BF C and AHMSA BF 6 All of these projects, each exceeding 200 M$, would not have been considered in the recent past.

Increased Furnace Productivity

When discussing increased productivity we have to divide our comments between the newer, larger furnaces designed for high productivity and the retrofitted smaller and typically older furnaces. The newer furnaces are designed to operate at low total fuel rates (and hence high productivity) via high temperature stoves, blast enrichment (fuel, oxygen), burden distribution equipment, high quality raw materials and enhanced charging and casting capability. The retrofitted furnaces have been provided with the process and raw material improvements to reduce fuel rate and increase productivity but it also has been necessary to upgrade charging and casting capability to accommodate increased hot metal production.

The following data indicate how high productivity is being achieved in a variety of furnace sizes using the full range of ferrous raw materials and injectants and operating in different plant environments in every part of the world.

Country	Furnace	Hearth Dia., M	Productivity T/M3/day	Burden	Injectant
Finland	Rukki BF1, BF2	7.2	3.4	sinter	oil
Sweden	SSAB Turnplat BF2	8.5	3.5	pellets	coal
Canada	AMDofasco 4 BF	8.5	2.9	pellets	PCI
USA	SeverstalNA BF C	8.8	3.1	pellets	PCI
USA	AK Middletown BF3	8.9	4.2	pellets, HBI,	gas
Belgium	AM Ghent BF A	10.0	2.8	sinter	coal
Argentina	Siderar 2	10.4	2.6	S/P/lump	gas
Japan	Nisshin Kure 1 BF	10.5	2.4	sinter	coal
Australia	BS Port Kembla BF5	12.0	2.5	sinter	coal
China	Wuhan BF5	12.2	2.0	sinter	coal
Netherlands	Tata BF7	13.8	2.7	sinter/	
	Ijmuiden BF6	11.0	2.9	pellets	coal
Brazil	CSN Volta Redonda	13.0	2.8	sinter	coal
Korea	Gwangyang BF's 1 - 4	13.2	2.7	sinter	coal
Japan	JFE Keihin BF 1	14.8	2.7	sinter	coal
Japan	Nippon Steel,Oita BF2	14.8	2.4	sinter	coal

A common feature of all of the operations shown above is excellent raw material quality. Fluxed pellets are prominent in the operation of the smaller furnaces while sinter is the predominant burden material in larger furnaces. High quality coke is common to all operations. The specific productivity values are almost all in the range of 2.5 to 3.4; in the recent past specific productivity levels of 2.0 - 2.5 were considered to be quite good. Exceptional productivity at AK is aided by charging metallics, mainly HBI at high rates, > 200 kg/T.

Reduced Total Fuel and Coke Rates

The increased productivity accomplishments outlined above have been primarily the result of the evolution of reduction of total fuel rate. The very large newer furnaces shown above were designed and built for low fuel rate operation but the designers of these furnaces had the benefit of the technical developments listed (adapted from [1]) in the following table:

Years	**Coke Rate** kg/T	**Injectant** kg/T	**Total Reductant** kg/T	**Comments, Developments**
1950	1000	0	1000	lean, local ores, no injectants
1965	600	0	600	rich, seaborne ores
1970	525	50	575	oil injection, high blast temperature oxygen enrichment
1980	500	50	550	high top pressure, burden distribution & permeability control
1990	400	125	525	coal injection, improved sinter, coke quality
2000	325	175	500	increased coal, gas, oil injection
2010	300	200	500	increase PCI, oxygen; lower possible fuel rates with metallics
2015	*250*	*250*	*500*	“

There has been a steady decrease in the average coke rate for North American blast furnaces from 1976 (625 kg/T) to 2000 (<400 kg/T). Part of this is attributed to a reduction in total reductant rate while a significant portion is attributed to increased levels of injection of auxiliary fuels such as coal and natural gas. North American progress is presented below:

Weighted (by Production Rate) Averages of Reductants by AISI BF’s (4)

	Hot Metal Production, M tonnes	# of Operating BF’s	Reductant Usage, kg/tHM Coke Lump	Nut	Total	Coal	Oil	Gas	Tar	COG
1990	55.55	60	454	1	455	1	12	23	3	0
1995	61.00	51	402	8	410	34	13	38	1	1
2001	51.92	45	395	24	419	59	9	17	3	2
2004	52.75	38	366	26	392	58	10	35	4	2
2007	47.85	35	377	28	405	65	9	27	2	2
2008	44.80	35	379	29	408	62	9	32	0	2
2010	41.80	33	376	32	409	73	2	39	0	1
2011	43.70	32	364	36	400	69	1	50	0	1
2012	44.10	32	376	30	407	52	0	63	0	0
2013	41.90	29	368	29	397	55	0	61	0	1

Some leveling off in progress is apparent; the growth of coal injection has been hampered by both capital cost constraints to build additional PCI plants and coal availability to optimize performance of existing coal injection facilities. Finally, we saw some renewed progress in PCI with new facilities at SeverstalNA and at AM Dofasco. However, the recent reduction in natural gas prices associated with the Marcellus Shale activity is leading to increased injection of natural gas such that any additional PCI projects are unlikely.

The key developments to reduce coke and total reductant rates are:

Burden preparation - the biggest single contribution has been the movement away from local, lower grade lump ores to agglomerated burdens of sinter and pellets with the primary ore sources being imported, if necessary, and clearly higher in Fe content and lower in gangue content. On a more selective basis, coking coal selection favored coals lower in ash and sulfur.

Auxiliary fuel injection, high hot blast temperature, oxygen enrichment, reduction of blast moisture - these blast enrichment and intensification developments were mutually reinforcing. Higher hot blast temperature increased energy input in the blast while saving on energy contained in top charged coke. Auxiliary fuel injection (oil, tar and natural gas) also replaced coke; the ability to inject more fuel was extended by increased blast temperature and oxygen enrichment. Oxygen enrichment also increased productivity.

Furnace top pressure, burden distribution equipment - increased furnace top pressure increased gas density and improved permeability while also increasing gas-solid contacting effectiveness. The latter was also improved by burden distribution equipment such as movable armor and the bell-less top which allowed for charging of ore and coke in a radially more uniform manner, thus facilitating uniform gas flow. These developments increased the level of reducing gas utilization and reduced the coke rate.

Improved sinter, pellet and coke quality - the development of improved fluxed sinter, along with the identification of RDI (Reduction-degradation-index) as a key sinter property, have been particularly important in most regions of the world where sinter is the predominant burden material. The shortage of high quality lump ore in these areas has been alleviated by use of pellets with improved chemical, physical and metallurgical properties. In North America and Scandinavia, fluxed pellets have played a key role. The importance of coke sizing and stability has long been known and the identification of the importance of coke reactivity and CSR (coke strength after reaction) has provided a further means to improve furnace permeability.

High-level coal and natural gas injection - the progression of coal injection technology, particularly in Europe, and natural gas injection technology in North America, has reduced coke rates significantly in the last decade. Coal injection systems are now being installed with the capability to inject 200 kg/T whereas the earlier generation of these systems, designed mainly to replace oil injection, injected in the range of 75 - 150 kg/T. At one time the level of natural gas injection was believed to be very limited due to its strong depressive effect on raceway flame temperature but experience in North America has shown that small to medium sized furnaces can operate at much lower flame temperatures.

Process control, instrumentation and computerized data display - these tools, aided by the high power and lower cost of computer hardware/software, enable furnace operators to diagnose furnace problems more readily and to optimize the furnace thermal level and burden and gas distribution. The full range of available instrumentation includes radial gas sampling and temperature probes, burden profile meters, top gas analysis, pressure taps and arrays of thermocouples to measure inwall and cooling water temperatures. The fuel rate is reduced through the setting of more aggressive targets for hot metal chemistry and blast conditions.

Extended Furnace Lining Life

Several decades ago furnace operators were resigned to the routine of relining furnaces every three to five years. The reduction in the number of furnaces in operation and the increase in capital cost has motivated the extension of furnace campaign lives to ten years or more. In some regions, the philosophy has switched from planning for long reline outages with complete refractory replacement to a strategy of a series of short, focused intermediate repairs when needed with complete relining only occurring when the furnace hearth needs to be replaced. The techniques used to maintain these extended campaigns include:

Enhanced cooling and refractory systems - both intensive plate cooling and stave cooling techniques continue to be refined. With plate cooling, the cost effectiveness of silicon carbide, graphite and semi-graphitic bricks has been demonstrated. Installations of copper staves in furnaces in Europe and elsewhere have been spectacular successes as demonstrated by negligible wear patterns and very stable low level thermal loads.

Remote repair methods - the ability to extend the time between outages and to minimize repair time has been greatly enhanced with techniques such as grouting (insertion of refractory material from outside the furnace), gunniting and shotcreting (the spraying of refractory material,), remote replacement of staves, and installation of auxiliary circular coolers; the concept of the "endless campaign" has been touted, limited only by hearth life.

Hearth life extension - since the hearth life is now the critical link to total campaign life, much attention has been given to both designing new hearth refractory and cooling configurations and developing hearth life extension techniques. The North American carbon brick, coupled with adequate cooling, has been conspicuously successful while use of ilmenite ($TiO2$), mainly by direct charging of lump ilmenite ore, has been effective.

Furnace operating stability - the improvements in furnace raw materials, burden and gas distribution and process control have led to stable furnace operation, which in turn minimizes damage to refractories and cooling elements.

Raw Materials Improvements and Flexibility

The underlying factor in this improvement has been a fundamental shift in raw materials sourcing philosophy driven by both iron production strategy and availability for both iron ore and coal.

Iron ore - sintering ore fines - historically iron ore was primarily sourced from local or regional mines; frequently this ore was low-grade but options were limited. In the last five decades the sea borne trade of iron ore has grown dramatically with higher-grade ore deposits being developed in Australia, Africa, South America, Canada, India, Sweden, etc, while the construction of large vessels has reduced shipping costs. The low delivered cost of high grade ore, coupled with the sintering and blast furnace process benefits of such ore, gradually led to the closure of low grade ore mining operations. For most of the world, the sintering process, based on high-grade ore fines, is the primary ferrous feed material. Mt.

Wright (Canada) concentrate is an example of such a high grade sintering ore; we note the high Fe content, moderate gangue levels and very low levels of deleterious impurities:

Chemical analysis, % dry Mt. Wright Concentrate

Fe	66.00	CaO	0.07
SiO_2	4.90	MgO	0.05
Al_2O_3	0.33	Na_2O	0.008
P	0.015	K_2O	0.008
S	0.005	LOI	0.05
Mn	0.025	trace amounts	
TiO_2	0.180	other elements	

Iron ore - pelletizing - in North America the depletion of rich ore reserves promoted the development of the pelletizing process, based on beneficiating low-grade ore not suitable for sintering. The decline in hot metal production in the 1980's coupled with excess but modern pellet plant capacity caused a reduction in environmentally threatened sintering capacity. The subsequent development of fluxed pellets and improvement of acid pellet properties have made pellets the prime feed material in North America and parts of Europe and a valuable supplementary feed material elsewhere. Typical pellet grades are those produced by AMMC:

	Blast Furnace Pellets			DR Grade
	acid	fluxed	low SiO_2 fluxed	pellets
Chemistry, %				
Fe	65.10	63.30	66.00	67.70
SiO_2	5.20	3.75	2.50	1.60
Al_2O_3	0.50	0.50	0.40	0.40
CaO/SiO_2	0.12	0.98	0.80	0.34
CaO	0.60	3.68	2.00	0.55
MgO	0.25	1.30	0.80	0.30

Such pellets have similar low levels of deleterious impurities as the Mt. Wright concentrate from which these pellets are produced. These pellets are characterized by excellent physical strength, close sizing, absence of fines and metallurgical properties able to support a 100 % pellet burden.

Coal - coking and injectant - shifts in coal sourcing have also occurred as steel plants with ocean access have shifted from higher cost, lower grade local coal sources to higher grade coal from locations such as North America and Australia. Improved coal quality has contributed to the improved coke quality, which is essential for the successful operation of large blast furnaces. High-level coal injection is also enhanced with the use of high quality coal.

Coke quality requirements - as furnace size and injectant rates have increased, the coke rates have decreased; together these trends require higher quality coke as indicated by large mean size, 50 mm, high stability, > 60 and high CSR (Coke Strength After Reaction).

Trends in Blast Furnace Ironmaking - North American Example - Dofasco

The experience of ArcelorMittal Dofasco in Canada is a North American example of progress in blast furnace ironmaking. Their furnaces, originally built in 1960 (7.3 m, BF 2), (6.6 m, BF 3) and 1971 (8.5 m, BF 4), have been selectively modernized in the charging, cooling & refractories, cast house and computer control areas to improve for availability, operational stability, productivity, fuel rate, hot metal consistency and hot metal cost. The furnace upgrades have been accompanied by raw material and practice changes such as the development of fluxed pellet burden (>70 % AMMC pellets), evolution towards lower slag volume operation and increased levels of oil injection (and now PCI and gas injection) and oxygen enrichment. The evolution of furnace productivity, coke rate & oil rate, total fuel rate, hot metal chemistry, slag volume and campaign life are shown below:

	1971	**1980**	**1990**	**2000**	**2013**
Productivity, T/M3/day	1.46	1.88	2.13	2.75	2.17
Coke Rate, kg/T	505	465	423	409	373
PCI Rate, "	-	-	-	-	111
Nat. Gas Rate, "	-	-	-	-	**24**
Oil Rate, "	87	105	53	62	-
Total Fuel Rate, "	594	570	476	471	508
Slag Volume, kg/T	269	233	208	192	191
Hot Metal Si, %	1.09	0.85	0.49	0.36	0.63
Hot Metal Mn, %	1.00	0.87	0.54	0.51	0.51
Campaign Life, MT	4.2	4.4	6.9	15.5	25+

ISSUES FACING BLAST FURNACE IRONMAKING

Ultimate Process Limits

Productivity - Dramatic gains in productivity and fuel rate have been realized in the past several decades, as shown earlier. Further gains in productivity, if justified by hot metal demand, can be realized with more widespread adoption of oxygen enrichment coupled with high-level coal or natural gas injection. The development of the high-level injection technologies along with the reduction in oxygen production costs (via reduced purity and co-generation systems) should promote higher productivity. Further productivity gains can be realized with pre-reduced materials such as scrap and HBI but the value added by additional hot metal must be weighed against the acquisition costs of these pre-reduced materials.

Injectant Rates - while coal injection rates of up to 200 kg/T have been demonstrated there appears to be a plateau around 170 - 180 kg/T beyond which the raw material and process challenges become significant. A key factor is the behavior of unburnt char elsewhere in the furnace. If coal combustion in the raceway can be further enhanced and if the behavior of residual char can be better understood and controlled, then extension of coal injection to 250 kg/T will be realized. Smaller furnaces have been shown to be operable at lower flame temperatures, but there may be some lower limit that would preclude economic injection of natural gas beyond 150 kg/T. However, a modest amount of gas, 20 – 40 kg/T, can be an effective co-injectant along coal injection to both moderate flame temperature and to avoid the challenges of very high coal injection rates. Under selected local economic conditions, the use of other injectants such as plastics, animal fats, biomass, etc, can be effective.

Coke rates - as the coal injection rate climbs to 250 kg/T, the coke rate will drop to below 250 kg/T, thus the ore/coke ratio will further increase. Two technical issues arise: the maintenance of liquid and gas permeability in the lower part of the furnace as coke forms the porous grid, and the impact of long residence times on the properties of coke and ferrous materials during their descent in the furnace.

Technical issues impacting ultimate process limits

Some key technical issues impacting the ultimate process limits were already discussed above:

- behavior of unburnt char in the furnace,
- upper (maximum oxygen enrichment) and lower (maximum injectant level) limits of raceway flame temperature,
- effect of high ore/coke ratio on permeability

Other key technical issues include:

- hearth phenomena at high injectant and productivity levels, including effect of unburnt char and transient phenomena associated with deviations in coke quality, slag chemistry, etc, as discussed by Dr. Lu in his lecture,
- limitations on heat transfer and chemical reaction at high ore/coke ratios and minimum stack gas flow rates

The above limitations are being addressed in a conventional manner by minimizing the slag volume through raw material initiatives as outlined in the next section. These limitations are also being addressed by novel modifications to the blast furnace process:

- A European initiative to explore an alternate flow sheet to develop a "nitrogen free" blast furnace; the key elements are the removal of CO_2 from a portion of the top gas; this top gas is then heated and injected into both the tuyeres and the top of the bosh,
- A Japanese initiative that includes charging composites of iron ore and coal, partially metallized sinter, etc, along with furnace modifications such as a reduction of shaft height, multiple levels of tuyeres, increased oxygen use, etc.

Both of the above initiatives are actually aimed at reducing CO_2 emissions by 50 % in ironmaking in response to the Kyoto accord.

Raw Material Issues

Iron ore issues – the ability to achieve the ultimate process limits mentioned above is affected by iron ore quality. One approach to increasing permeability in order to maximize coal injection rates is to reduce slag volume. This is being accomplished by:

- **reducing sinter SiO2 levels** by selecting ores with lower SiO2 content. Formerly, sinter SiO2 levels had been maintained in the range of 5 – 6 % in order to maintain strength. Current sintering technology is aimed at maintaining sinter strength with SiO2 levels in the range of 4 – 5 %,
- **utilizing pellets with lower SiO2 content**, particularly for burdens with a high percentage of sinter; the AMMC low silica fluxed pellets shown earlier are an example.

Permeability and overall performance are also being improved by restricting the overall amount of lump ore in the burden, increasing sinter RDI (Reduction-Degradation Index) strength and improving pellet quality (screening, using fluxed pellets, etc).

Raw materials availability – the explosive growth in pig iron production in China has led to worldwide shortages of sintering ore, pellets, coking coal, coke and metallics including scrap and DRI. This growth has also led to record high ocean freight rates. These raw material shortages could lower the growth in pig iron production while steel companies lacking secure sources of raw materials are facing sharp increases in raw material costs. Fortunately, most North American ironmakers, with access to North American pellets and local coke production, have been relatively shielded from these problems. Scrap based mini-mills and global integrated producers relying on the seaborne ore and coal trade have faced higher cost increases than most North American blast furnace based steel companies. On a longer term basis, we can say that the reserves of iron ore and coking coal are more than adequate to sustain ironmaking but investment is required to extract these materials. The price increases for ore and coal over the past decade are providing funds for such investments.

Agglomeration facility (sinter vs. pellet) issues – pellets are the dominant burden material in North America while in Europe, much has been written about possible sinter plant closures due to environmental reasons. Almost all sinter plant closures have been at plants facing imminent shutdown of primary facilities or very small, old sinter plants. On the other hand, the large, competitive sea-borne blast furnace plants in the UK, France, Germany, Belgium, etc, have actually increased sinter plant output by physically expanding sinter plant grate area, re-starting idle sinter facilities and optimizing sinter process and raw material conditions. Sinter is still the material of choice for tonnage BF plants worldwide with access to seaborne iron ore. From a process perspective it has been demonstrated (4) that equally good blast furnace performance can be obtained with fluxed sinter or fluxed pellets as follows:

2002 Results	**Sparrows Point L Furnace**	**ArcelorMittal Indiana Harbor 7 Furnace**
Hearth diameter, m	13.5	13.7
Burden, kg/tHM		
Sinter	1040	228
Acid Pellets	534	0

Fluxed Pellets	0	1350
Lump ore, siliceous ore, etc	48	13
Reductant use, kg/tHM		
Large coke	316	319
Small coke	24	22
Coal	149	155
Natural gas	1	0
Top gas utilization, %	50.4	49.2
Slag volume, kg/tHM	270	265

Recycling Waste Oxides – sinter plants recycle the majority of steel plant waste oxides, including steelmaking slags, mill scale, dusts and some sludges. Materials not suitable for sintering such as oily mill scale, BOF dusts, sludges, etc, are stockpiled, land filled or are fed to alternative processes. For most North American steel plants, a sinter plant is not available so a number of plants have installed cold briquetting facilities. However, these materials, which lack high temperature properties, can only be used as a small (< 5 %) part of the burden. A potentially more promising approach is the installation of prototype rotary hearth furnace (RHF) direct reduction plants in North America and Japan. These RHF plants produce DRI (or HBI) that could be utilized in BF but mainly in steelmaking furnaces. Such plants can consume waste oxides not suitable for sintering, as well, and should have an overall positive impact on blast furnace economics. Some RHF plants are operational in Japan but the only one installed at a blast furnace site in North America has been dismantled and shipped overseas.

Facility Maintenance, Modernization, and Anticipated Lifespan

The high capital cost precludes the construction of new furnaces except in certain situations. The majority of blast furnace capital will continue to be spent on rebuilds, relines, and repairs, with opportunities being sought for selective upgrading of furnace cooling & refractories, charging systems, cast floor equipment, coal injection systems and instrumentation & computer facilities. The extent of upgrading will be affected by assumptions as to the anticipated lifespan of the blast furnace facilities. This will be mainly influenced by the **overall competitive position of the steel plant** in which the furnaces are located. For example a permanent blast furnace plant shutdown in 2000 in the USA was driven by poor economy of scale and limited steel product quality even though hot metal costs were competitive (< 125 $/NT at that time). The resurgence of the competitive position of North American blast furnace based steel production has led to essentially new blast furnaces being built as listed earlier. Nevertheless, blast furnace shutdowns continue in North America, as evidenced by the demise of the 3 BF sites of RG Steel; all 3 plants were non competitive in finished product quality and selection, even though one of these sites featured the large L BF, noted earlier.

Environmental Issues: Aging Coke Ovens, Threatened Sinter Plants

While the blast furnace itself has been able to attain compliance to environmental statutes with appropriate upgrading of gas cleaning, water purification and casthouse emission systems, the facilities providing blast furnace raw materials are under intense pressure. Coke plant environmental efforts have consumed considerable capital but the latest round of environmental regulations still threatens the future of cokemaking in the U.S.A. The high capital cost of coke ovens coupled with the environmental risk had slowed down coke oven construction and rebuilding in North America and Europe. . The decrease in coke rates with high-level coal injection (and gas injection in the USA) and other techniques and availability of imported coke had been keeping this problem under control. However, very high imported coke prices in 2003/2004 motivated the building of heat recovery coke batteries in Haverhill and Middletown, Ohio and Granite City , Illinois along with the rebuild of slot oven batteries elsewhere. In Europe, sinter plants, which provide the majority of the ferrous burden, are under environmental pressure related to dioxins and NOx.

Interaction with Downstream Processes

The reduction in the number of operating blast furnaces, the enlargement of steelmaking shops, and the nearly universal adoption of continuous casting has simplified in-plant material flow, but has removed flexibility from the system. Any interruptions or delays in casting or steelmaking quickly cause a build-up in hot metal inventory. Thus many blast furnace operations are faced with start-stop modes dictated by downstream processes. Some plants have installed pig-casting facilities to produce pig iron during such interruptions. The cold metal produced can be either used later in the same plant or sold externally as the need for virgin iron units in EAF operations provides a new market.

Blast Furnace Hot Metal Costs

The competitive position of blast furnace ironmaking is strongly determined by hot metal costs. Low costs are favored by: water receipt of raw materials, captive on-site coke production, equity in pellet plants coal injection facilities, low natural gas, oil prices, economy of scale: larger furnaces, multiple furnaces, process efficiency (low coke rates, high specific productivity, etc), outsourcing of ancillary functions – slag handling, maintenance, etc. Conversely, costs are increased by: rail receipt of raw materials, purchased coke, coke transport costs, purchased pellets, high natural gas, oil prices, scale: smaller furnaces, single furnace plant, ancillary function costs – slag handling, maintenance, high corporate overhead, etc.

CHALLENGES CONFRONTING BLAST FURNACE IRONMAKING

The challenges to blast furnace ironmaking include coke supply and alternate process routes, which will be covered in the following section. These alternates include alternate hot metal processes, the electric arc furnace (EAF) steelmaking route and the strategy of using slabs from outside sources.

Coke Supply and Cokemaking

Up to now the single most critical challenge facing blast furnace ironmaking has been the supply of coke. Another facet of this challenge is that coke has to be of the highest quality to enable furnace operation at high specific productivity at progressively lower coke rates as coal and gas injection levels are increased. <u>Recent developments have relaxed this challenge, somewhat</u>:

Rebuilding slot oven coke batteries - although environmental control equipment coupled with dedicated preventive maintenance programs can yield a clean, efficient battery operation, the uncertainty of future regulatory policies is still a major constraint. Highly competitive blast furnace plants should still consider rebuilding coke batteries such as the rebuilds at ArcelorMittal Burns Harbor and ArcelorMittal Dunkirk in the past decade. The repairs at Mountain States Carbon (owned by Severstal NA JV) are encouraging along with the rebuilds at USS Clairton.

Beehive or sole heating type coke oven construction offers environmental benefits along with the flexibility to use a wide range of coal types. Such ovens require energy recovery facilities. In North America, the Indiana Harbor Coke Company (IHCC) heat recovery coke battery**,** started up in 1998**,** was a significant step. This 1.2 MT/yr. coke plant supplies high quality coke to the ArcelorMittal Indiana Harbor East (ex- Inland) BF 7 that is producing 11,000 tons/day of hot metal. Other heat recovery coke plants have been built in Haverhill, Ohio, Granite City, Ill and Middletown, Ohio as well as in Brazil.

Purchasing coke from offshore sources (China, Poland, Japan, Ukraine, etc**)** has helped with coke shortages and has proven to be more viable than originally envisioned. Chinese coke producers are now developing more environmentally friendly coke production processes to maintain a leading role as coke exporters.

New cokemaking technology – the most recent developments include the novel Carbonyx process where two 250 KT/year modules were built at USS Gary and are facing ramp up challenges.

It now appears that the threat to coke supply for blast furnace operations is perhaps less than projected in the recent past. Commercially feasible new technologies such as heat recovery cokemaking, rebuilds of existing batteries and novel cokemaking technologies along with available imported coke (if needed) should minimize the coke shortage threat to blast furnace ironmaking.

CHALLENGE OF ALTERNATE PROCESS ROUTES

<u>Development of Competitive Processes & Process Routes</u>

The major driving forces for development of competitive processes such as smelting reduction processes are to avoid the cokemaking and sintering steps preceding the blast furnace. The blast furnace process itself is now well recognized as a very efficient process such that any new process can only approach but not surpass the blast furnace for efficient production. We can offer some observations on smelting reduction (to feed BOF's) and alternate steel processing routes, mainly involving EAF's:

Smelting reduction - Corex - only the Corex (and now the Finex) process is commercially proven, but only up to 3000 T/day using a high percentage of pellets, (*Finex is producing 4,000 tons/day using ore fines*) and reportedly also a small amount of coke. Although the Corex process has been criticized for the above limitations and high capital cost, it must be recognized that the process is less than two decades old and there is much time available for evolutionary improvement. The blast furnace process has been evolving over hundreds of years, by comparison.

Smelting-reduction - HIsmelt - The bath smelter segment of the **HIsmelt** process had been coupled to a circulating fluid bed pre-heat/pre-reduction step using iron ores. A commercial HIsmelt plant (0.8 MTPY capacity) started up in 2005 in Kwinana, Australia. This project involved JV partners: Rio Tinto, Nucor, Shougang, Mitsubishi; the plant was producing (at > 75 % capacity in early 2008) merchant pig iron using Australian higher phosphorus iron ore. The plant was shut down and later dismantled and reportedly moved to China?

ISARNA process - The HIsmelt bath smelter segment is now being coupled to a pre reduction process called the CCF (Cyclone Converter Furnace) in the ISARNA process, part of the ULCOS program in Europe. A demo plant is being operated at Tata Ijmuiden.

Direct reduction/scrap/EAF steelmaking route - the EAF mini-mill route is now suited for flat-rolled steel production with the move up the quality ladder strongly dependent upon feed of virgin iron units to the EAF. The shaft furnace DR processes such as **Midrex** and **HyL** are well established but dependent upon DR grade iron ore pellets. The fines-based processes have attracted much attention but only one VAI **FINMET** plant remains in commercial operation; such a plant was built with very high capital costs.

DRI/scrap/EAF route vs. BF/BOF route - With the DRI/EAF process route identified as a competitor to the blast furnace process, the key factor is natural gas pricing for the established Midrex or HyL processes. Where natural gas is available at less than $ 2/MSCF, there can be an overall economic advantage for the DRI/EAF route. The economics of coal based DRI are not attractive enough to be competitive in areas with high gas prices.

Hot metal/EAF steelmaking route – this route could rely on hot metal from nearby blast furnaces or new on-site hot metal processes. An example of the latter is at Steel Dynamics where the **Iron Dynamics (IDI)** Process (to be described later) is feeding hot metal to an EAF. An example of the former is the Consteel EAF vessel installed (to replace one of two blast furnaces and one of three BOF vessels) in Steubenville, Ohio. This EAF could use 30 – 40 % hot metal from the remaining blast furnace; actual hot metal consumption is a function of relative scrap and hot metal costs. This plant is now idle.

Alternative iron/scrap/EAF steelmaking route. Although these DRI/hot metal/scrap/EAF developments are promising, the liquid steel cost comparison still favors the large tonnage, coastal BF/BOF process route over the alternative iron/EAF route; however final steel product costs can be lower, particularly in North America, with the mini-mill route due to the following: absence of legacy costs, management culture including limited corporate overhead, and simplified rolling and product handing facilities. Accordingly, competition with EAF flat-rolled mini-mills will still be an issue for blast furnace producers. The current high prices for scrap, pig iron, HBI, etc, have tilted the balance in favor of blast furnace hot metal production, particularly for those companies which have been financially re-structured. However, low natural gas prices have motivated the addition of 4.5 MTPY of DRI capacity (Nucor and Voest Stahl) in the USA, with additional DRI projects under study; this could favor the DRI/EAF route in the future.

Future process routes - a possible future process route is feeding of hot metal from a moderate scale process such as the RHF/SAF, HI-Smelt or other process to an oxygen enhanced steelmaking vessel that is a hybrid of an EAF and a BOF or LD converter.

Summary of Direct Reduction Processes

The above discussion mentioned a number of alternate hot metal and direct reduction processes. For clarification and reference purposes we will elaborate further on these processes. We will first discuss processes to produce DRI or HBI with the aid of the following table:

DIRECT REDUCED IRON (DRI/HBI) Processes

Reductant:	coal-based			gas-based	
Vessel:	Rotary Kiln	Rotary Hearth	Fluid Bed	Shaft Furnace	Fluid Bed
Iron Ore:	lump ore	fines	fines	pellets, lump ore	fines
Process	**SL/RN** **DRC** **others**	**Inmetco** **Fastmet**	Circofer	**Midrex** **HyL**	**FINMET** Iron Carbide Circored

All processes that have attained commercial status are shown in bold.

Established processes - Worldwide DRI/HBI production is dominated (> 75 %) by the gas based shaft furnace processes (MIDREX, HyL, etc) using pellets and lump ore. For regions with low cost, local coal and iron ore, such as India, South Africa, China, etc, the smaller scale coal-based DRI processes will continue. Coal based DRI processes have been studied in North America but the EAF penalty for coal ash and gangue along with economy of scale issues are too difficult to overcome for merchant (or even captive) plants producing DRI as an end product. However, the coal based DRI process can feed a hot metal process where the coal ash and sulfur (and ore gangue) are removed by the slag. However, low natural gas prices favor the shaft furnace DRI processes so the existing coal based pig iron plants (IDI, Mesabi Nugget) will continue but no new coal based plants will be built in the USA..

Fines-based processes - These have attracted much attention but have not established themselves: the two Iron carbide plants and the BHP FINMET plant have been dismantled while the Outotec Circored plant remains idle. Only the Orinoco Iron FINMET plant remains in operation. These two VAI FINMET plants have been built with very high capital costs. One of the driving forces for fines-based direct reduction processes is the avoidance of the pelletizing processes. The economic incentive is the cost differential between pellets and fine ore, typically > $ 20/Fe ton but now over $ 40/Fe ton. However, the challenges (higher capital costs, energy consumption, dust losses, etc) posed by fluidized bed processes have essentially eliminated this initial cost differential. The fines-based direct reduction processes that are currently being commercialized are mainly the rotary hearth furnace (RHF) processes for waste oxide processing and the RHF segment of the IDI hot metal process. However, these RHF processes do involve an agglomerating (pelletizing or briquetting) step to prepare feed for the RHF. The concern about pellet availability for the shaft furnace processes has been met by increased output and quality initiatives from mining companies worldwide.

MIDREX, HyL Progress and Issues - these processes have responded to the challenges of competitive processes and process routes with continuous improvement in scale, efficiency, flexibility, etc. The evolution of the MIDREX process could be similar to that described earlier for the blast furnace process, but over a shorter time frame. For example (11), productivity in a standard sized Midrex module has increased from < 90 to nearly 130 tons/hour, an increase of > 45 % while electricity consumption has decreased from 135 to < 95 kwh/T, or about 30 %.

One major issue for the MIDREX and HyL processes in North America has been the natural gas pricing. With gas consumption at roughly 10 MMBTU/NT, a gas price increase from 2.00 to 7.00 $/MMBTU raises the energy cost from 20 to 70 $/T, making DRI less competitive with other metallics. In 2001 no MIDREX facilities were operating in the USA and Canada while several in Mexico were also idle, all due to high gas prices. The captive DRI plants are operating in Mexico and Canada but the one plant in the USA had been abandoned. Also two part-merchant, part-captive DRI plants have been relocated to low gas cost regions: AIR to Trinidad as NuIron and Corus Mobile to Saudi Arabia (Al-Tuwairqi Steel). However, the sharp drop in gas prices due to the Marcellus shale development has led to a resurgence in interest in USA gas based DRI production. Prominent examples, mentioned earlier, are the Nucor and Voest Stahl projects; other projects are being studied.

Summary of Hot Metal Production Processes

The process routes for hot metal production can be divided into two types:

Single Vessel Processes - blast furnace, cupola, smelter

Multi-vessel processes - production of DRI followed by smelting or melting step: Corex, HIsmelt, RHF/SAF

HOT METAL Processes

Reductant:	coke	coal-based ------------------------------------		
Vessel:	Blast Furnace	Smelting-Reduction	RHF/ SAF	RHF
Iron ore type:	Pellets/lump sinter	fines pellets/ lump	fines	fines
Process:	**Blast Furnace** **Mini BF** “Low CO2” Blast Furnace **Cupola** - scrap - waste oxides	**Corex** <u>large scale</u> HIsmelt ISARNA, CCF AISI DIOS **Finex** <u>small scale</u> Romelt, AuIron , Tecnored	**IDI,** Fastmelt Redsmelt, **Primus** (multiple hearth)	**ITmk3**

We have classified the hot metal processes according to reductant type, vessel type and iron oxide raw material. **All processes that have attained commercial status are shown in bold.**

Commercial processes - The **blast furnace** is the dominant hot metal process worldwide while the **mini blast furnace (MBF)** plays a role both in small scale steelmaking (EAF or BOF feed) and in production of merchant pig iron, mainly to feed EAF’s. The **cupola** is mainly used on a smaller scale as a melter of already reduced materials such as scrap but some current applications (**OxyCup** Process) are aimed at processing self-reducing agglomerates of waste oxides. As noted already, **COREX and Finex** are the only commercial smelting-reduction process. These have a niche as a processor of high alkali ores. The development of the **Finex** option (fines-based) is welcome but further scale up and a reduction of capital cost is needed before it can compete with the blast furnace process. The first two Posco **Finex** plants are rated at 0.8 and 1.5 MTPY while another Finex plant at 2.0 MTPY capacity nears start up. COREX is suitable for small scale ironmaking if the off-gas is used for power generation or as a reductant in shaft furnace DR processes.

“Low CO2 Blast Furnace” - this refers to European and Japanese research initiatives to modify the blast furnace by equipment changes: “nitrogen free flow sheet” including stack injection, recycled top gas, reduced shaft height, etc and by raw material changes: ore/coal composites, metallized sinter, etc. These efforts are aimed at reducing CO2 emissions by 50 % ; implementation has been delayed by EURO zone economic problems.

Other smelting reduction processes - The other large scale processes listed above, DIOS**,** AISI, CCF**,** are all dormant. These did have pre-reduction steps, but were higher risk and not as well suited to EAF plants. However as noted above, CCF, Cyclone Converter Furnace, is being revived by coupling it to a HIsmelt vessel in the ISARNA project sponsored by

ULCOS in Europe. AusIron has now been acquired by Outotec as a smelter step for their Circofer or Circored pre reduction processes. Romelt has not advanced due to the lack of a strategic partner. A small commercial Tecnored (has greenball step) plant was built in Brazil but now taken over by VALE with the demo plant relocated to the Sao Paolo area.

Iron Dynamics (IDI) hot metal process - The first North American stand-alone hot metal plant dedicated to EAF application is the IDI Plant at the Steel Dynamics Plant in Butler, Indiana. The Iron Dynamics, Inc (IDI) plant has been re-configured following its 1999 start-up and subsequent difficult operation. The IDI process concept originally combined the rotary hearth furnace (RHF) direct reduction of a composite iron ore/coal greenball followed by submerged arc furnace (SAF) melting of this DRI. The IDI process has been reconfigured with briquetting replacing greenballing as the RHF feed preparation step. The briquetting step facilitates the use of waste oxides including mill scale, dusts and sludges; this reduces input iron and carbon unit costs. The plant produces about 250 KT/year of hot metal.

Proposed similar RHF/SAF-type processes – these are the Midrex Fastmelt and Paul Wurth Redsmelt processes along with the multiple hearth furnace Primus process. Midrex has commercialized the RHF portions of its process via waste oxide plants in Japan. A demonstration Redsmelt plant has been operated at the Piombino plant in Italy. Commercial scale Primus plants are operational in Luxembourg to process EAF plant waste oxides and in Taiwan at a BF/BOF plant.

ITMk3 (Iron Nugget) Process – another development is the ITMk3 rotary hearth process to produce pig iron nuggets for EAF charging. This process involves the greenballing of iron ore and coal fines, followed by reduction of these greenballs in a rotary hearth furnaces where temperatures are high enough to effect melting and slag separation into pig iron and gangue; subsequent magnetic screening steps ensure production of a pig iron nugget suitable for use in an EAF. The first commercial Mesabi Nugget plant in Minnesota is in an extended ramp up phase.

Use of Hot Metal in EAF's – Since much alternate hot metal process development is aimed at feeding EAF's it is worthwhile to discuss this further. The issues with hot metal use in the EAF include scale; hot metal should be used as 30 – 40 % percent of the charge, but in order to have a reasonable scale for the hot metal plant (0.5 to 0.8 MT/yr.) a large EAF steel plant size (> 1.5 MT/yr.) is required. Accordingly, hot metal is not an option for smaller mini-mills unless a nearby hot metal source is available. The EAF itself also has to have the proper modifications to permit timely and safe charging of hot metal. These methods could include top charging through the roof, charging through a chute inserted into the slag door or charging continuously through a side launder.

Obstacles to Alternate Hot Metal Process Development

Inspection of the table in the preceding section indicates that few of the alternate hot metal processes have attained commercial status. The barriers facing commercial implementation include the following:

Fundamental Technical Challenges
Engineering, Scale-up, Maintenance
Competing Process Routes
Competing Alternate Iron Materials
Changing Economic Conditions
Need for Long –Term Financial Backing
Need for Strategic Partner

Fundamental Technical Challenges – these may be classified according to process type:
smelting reduction processes:
attack of refractories by FeO-rich slag, low carbon efficiency, high gas volumes, high coal
rates, drainage of liquids due to absence of coke, high dust losses with fines-based processes, ➔ high capital costs
fluidized bed processes:
drying, pre-heating of ore fines, sticking of iron ore fines, temperature control, dust losses, gas cleaning, handling, product discharge
RHF/melter, RHF/smelter processes:
production of consistent DRI, production of quality greenballs, briquettes, materials handling, process control of coupled processes, gas cleaning

Engineering, Scale-up, Maintenance – the shortcut of moving directly from pilot to commercial scale without a demonstration plant contributed to problems for the following processes: Iron Carbide, Circored and Iron Dynamics (RHF/SAF). Other issues relating to proper scale for a hot metal plant and requirements for real estate, etc, were discussed earlier.

Competing Process Routes – continuous improvement of the two major, established competing routes:
Continuous evolution of blast furnace process for large coastal BF/BOF plants
DRI/EAF steelmaking route:
continuous improvement of gas-based direct reduction processes (as discussed earlier)
competitiveness of this route in regions with low gas prices – Mid-East, Venezuela

Competing Alternate Iron Materials - these include scrap, DRI, HBI, and pig iron; steelmakers will prefer to buy these materials if prices are low enough to avoid investment in on-site processes; these materials will be evaluated according to value-in-use, also liquid hot metal from nearby sources will be preferred over on-site production.

Changing Economic Conditions – this refers to changes in prices of process inputs for new hot metal processes such as coal, natural gas, iron ore, electrical energy, etc as well as changes in prices of competing materials.

Need for Long –Term Financial Backing, Need for Strategic Partner – these are grouped together and the following listing of processes already developed (shown in bold print) or with a high chance of success, mainly indicate significant corporate support:
O **Corex, Finex** – VAI, Posco

- O HIsmelt – Rio Tinto; JV Partners: Nucor, Mitsuibishi, Shougang
- O **Iron Dynamics** – SDI
- O **Fastmet**/Fastmelt, **ITMk3** – Kobe
- O **Primus** –ArcelorMittal/Paul Wurth SMS

Competitive Strategy of Using Outside Slabs

The future of the blast furnace is also affected by steel company strategies that include use of purchased slabs to supplement or replace on-site steel production. Slabs could come more competitive domestic plants but mainly from off-shore low cost producing areas: Brazil, Venezuela, Mexico, Australia, the former Soviet Union (favored by liquidating facilities). U.S. semi-finished steel imports (mainly slab) have approached the levels of 10 MT/yr as steel makers exploit purchased slabs as a lower cost alternative to keeping aging equipment in service. North American slab buyers include companies that lack steelmaking facilities such as California Steel Industries and also steelmakers such as AK Steel, ArcelorMittal USA, etc. Nearly 5 MT of new merchant slab capacity (in South America, Mexico, China) has been added. One limit to this approach is that flat-rolled steel companies need to control melting to ensure quality for the most demanding customers. We can also observe that existing blast furnace plants in North America benefit from:

- fully depreciated facilities,
- high labor productivity, < 1 man-hour/slab ton
- North American coal sourcing and iron ore pellet plants.

Any new off-shore slab project has to overcome the above while also providing for capital recovery and ocean freight costs. The latest attempt with this concept is the CSA project in Brazil coupled to the Calvert, Alabama finishing mill. This was originally a JV of TKS in Germany and VALE in Brazil. The CSA slab plant was costly to build (6 billion dollar CAPEX) and operate; the finishing mill was sold to a JV of ArcelorMittal/NipponSumitomo. This mill will still receive some slabs from the CSA slab plant but many slabs will come from ArcelorMittal steel plants in the USA, as well as from ArcelorMittal plants in Mexico and Brazil.

CONCLUSION

Advancements in technology and raw materials have led to dramatic improvements in blast furnace productivity, fuel rate and campaign life thus presenting a moving target for competitive processes at which to aim. The environmental threat to coke oven operations continues, but new cokemaking technology and imported coke are playing a positive role, thus reducing coke supply to a cost issue. A major challenge to blast furnace ironmaking is the DRI/hot metal/EAF flat rolled mini-mill route. The in-place capital of coke oven and blast furnace facilities will ensure their dominance at least through 2020; however new coke producing facilities will be needed and are being built. It can be concluded that the blast furnace process has demonstrated flexibility and adaptability to changing conditions in the steel industry.

Beyond 2020 we could see:

- an emerging technology: smaller alternative hot metal facilities (RHF/SAF, HI-Smelt or other) feeding an oxygen-enhanced EAF vessel and/or,
- the current research efforts to "reduce CO2 emissions by 50 %" leading us to the next frontier in blast furnace ironmaking.

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