TECHNICAL PROGRESS IN NORTH AMERICAN IRONMAKING

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Abstract

The favorable economic conditions for the North American steel industry continue with the advantages of captive iron ore, coal and coke resources and favorable currency changes. Technical progress in ironmaking will be discussed in: ironmaking raw materials including pellets, blast furnace ironmaking, direct reduction and alternative ironmaking to feed electric arc furnaces and for waste oxide processing.

Key words: Ironmaking; Iron ore; Pellets.

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1 INTRODUCTION

The authors had the privilege of addressing(1) the 2nd Ironmaking and the 1st Iron Ore meetings in Vitoria in 2004. The status of the blast furnace based steel sector in North America was already changing in a dramatically positive way even at that time; the changes are now clearly observed.. Furthermore, the EAF based steel sector now plays an expanded role in North American ironmaking; The role of integrated DRI/EAF steel producers in Mexico, USA and Canada will also be discussed here following our outline of blast furnace ironmaking.

2 BLAST FURNACE IRONMAKING

2.1 Overall Economic Setting

The authors reviewed the major economic factors affecting blast furnace based ironmaking earlier(2,3) The highlights are summarized below.

North American hot metal production decreased by nearly 50 % from the 70's into the 90's with both external (competition from imports and EAF mills, currency changes) and internal (required environmental spending, high labor and legacy costs, depreciating facilities) factors contributing. A significant percentage of companies in this sector were under creditor protection during the first part of the current century. The liquidation of several such steel companies sparked the following: financial restructuring, manpower reductions, consolidation: that, when combined also with the following favorable external factors, have led to a resurgence of the blast furnace based sector:

Role of China - The favorable external factors are led by the "China boom" that increased global demand (and prices) for steel along with favorable currency swings. The China boom also sparked a surge of demand for commodities such as iron ore and coal that in turn sharply increased prices (and ocean freight rates) for these commodities.

Raw material positioning - The above increases in the prices of raw materials and ocean freight also changed global steel competitive dynamics by dividing steel producers globally into two groups: the "haves", those with ownership or local access to ironmaking raw materials and the "have nots", those relying on the seaborne trade for raw materials; here the high freight rates further erodes their competitive position. The North American blast furnace based companies clearly fall into the "have" category with greater than 90 % of the iron units coming mainly from North American ore mines and pellet plants while more than 95 % of the coking and injected coal coming from North American mines. North American coke capacity is still sufficient to supply over 80 % of the coke requirement, and with several new coke and PCI projects underway, this will only improve. The blast furnace hot metal/liquid steel cost position has also been favorable relative to the EAF mills given the current record high prices for scrap and scrap substitutes: pig iron, HBI, DRI, as follows:

Metallics market – the competitive position of blast furnace based steelmaking has been improved by the structural changes in the metallics (mainly scrap) market that have increased the relative costs of EAF based steel production: the prompt scrap supply/demand dynamic has shifted negative due to a number of factors:

Nearly universal adoption of continuous casting, improved rolling mill yields, improved yields in steel product manufacturing, depletion of reservoirs of scrap in areas such as the former Soviet Union, major additions of EAF capacity globally even in regions with no scrap supply, increased information and mobility of scrap trade, etc.

2.2 Blast Furnace Production

Hot metal production - The dramatic change in North American ironmaking in the past two decades can be illustrated in the following figures that summarize hot metal production by company in 1993 and again in 2007. In Fig. 1 we count 19 companies in 1993 with blast furnace operations but more than half of these operated only one or two furnaces. In 2007, by contrast, as seen in Figure 2 we count only 7 companies with blast furnace operations, however, all but three have only one or two furnaces. Two of the exceptions, ArcelorMittal and USSteel, dominate hot metal production on a tonnage basis with 57 % of the production from 25 furnaces. The disappearing company names from Figure 1 include final plant shutdowns (Acme, Gulf States, McLouth, Geneva and Weirton), name changes and consolidations.

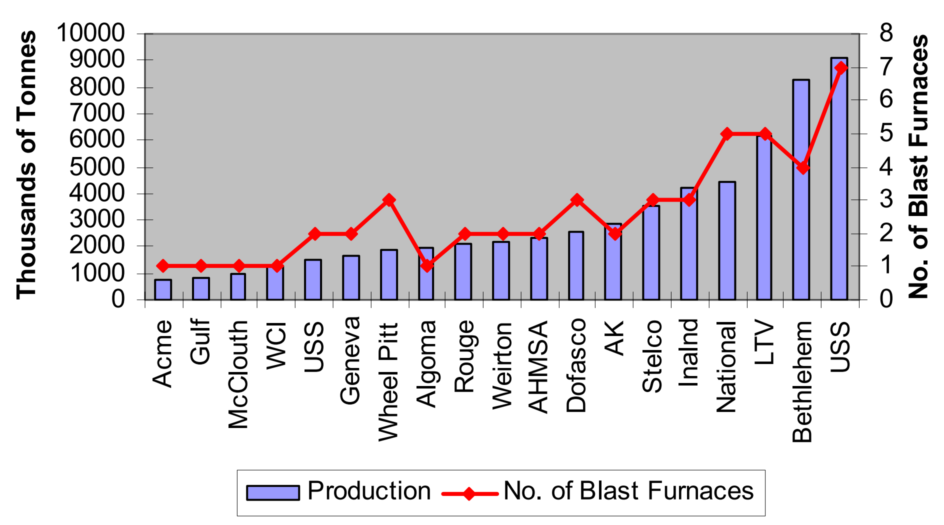

Figure 1: North American Ironmaking – Year 1993; Source- A.I.S.I.

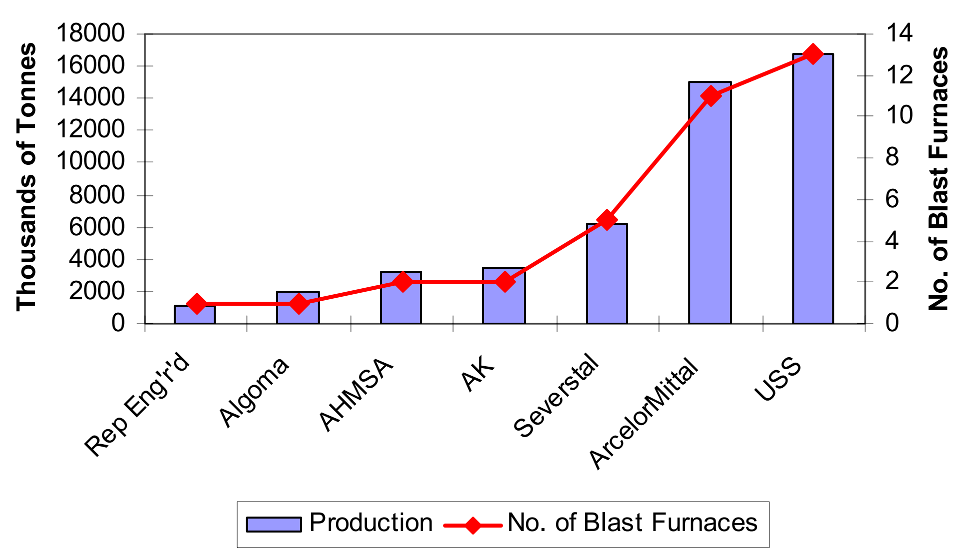

Figure 2: North American Ironmaking – Year 2007, with 2008 Organization; Source- A.I.S.I.

AK steel remains the only non global blast furnace operation. REP, the only long product BF plant, is part of the SIMEC Group of Mexico. Algoma is now part of Essar. In Table 1, we list the North American blast furnaces operated in 2007 with information on size, charging system, production, ferrous burden and type of injectant. We have grouped the furnaces according to the ownership structure as of June, 2008.

Table 1: North American Blast Furnaces – 2007

Company	Fce	H.D.	W.V.	Chging	2007		2007 Burden				Injectant
	I. D.			Control	thm / 24 Hrs	t / m3	Pellets		Sinter	Ore &	Used
		m	m³	Device		by WV	Flux	Acid		Other	2007
CANADA											
Algoma											
S Ste Marie, ON	7	10.66	2367	PW	9561	2.6	99	0	0	1	NG
Arcelor Mittal - Dofasco											
Hamilton, ON	2	7.30	1062	PW	2788	2.6	76	22	0	2	NG , O
Hamilton, ON	4	8.53	1595	PW	4215	2.6	76	23	0	1	O
US Steel - Stelco											
Hamilton, ON	E	9.80	1833	PW	4608	2.5	0	87	7	6	C , NG
Nanticoke, ON	LEW 1	10.28	2418	PW	5541	2.6	0	90	0	10	NG , T
MEXICO											
AHMSA											
Monclova, COAH	4	6.40	1034		3189	3.1	0	36	54	10	C , NG
Monclova, COAH	5	11.19	1914	PW	6442	2.9	97	1	2	0	C , NG
Arcelor Mittal											
Lazaro Cardenas	1	9.00	1649	PW	4500	2.8	90	0	0	10	C
U. S. A.											
AK Steel											
Ashland, KY	Amanda	10.18	2039	MA	4639	2.3	90	0	0	10	C , NG
Middletown, OH	3	8.93	1462	MA	5948	4.1	81	0	0	19	NG
Arcelor Mittal											
Burns Harbor, IN	C	11.65	2461		5402	2.2	0	67	32	1	C , NG
Burns Harbor, IN	D	10.89	2437		6087	2.5	0	66	33	1	C , NG
Cleveland, OH	C5	8.99	1546	MA	3807	2.5	10	81	0	9	NG , O
Cleveland, OH	C6	8.99	1598	PW	3570	2.2	22	72	0	6	NG , O
Indiana Harbor, IN	IH 3	8.99	1586	MA	3782	2.4	0	80	15	5	NG , O
Indiana Harbor, IN	IH 4	9.98	1918	MA	4388	2.3	0	79	18	3	NG , O
Indiana Harbor, IN	IH 5	8.08	1349		2170	1.6	66	27	0	7	C , NG
Indiana Harbor, IN	IH 6	8.08	1323		1704	1.3	65	27	3	5	C , NG
Indiana Harbor, IN	IH 7	13.72	4163	PW	10408	2.5	85	0	12	3	C
Republic Engineered Products											
Lorain, OH	4	8.83	1440		3506	2.5	0	91	0	9	NG , O
Severstal											
Dearborn, MI	B	6.09	794		2512	3.2	93	3	0	4	NG
Dearborn, MI	C	9.23	1798	PW	4106	2.3	93	2	0	5	NG
Sparrows Point, MD	L	13.49	3762	PW	7896	3.2	0	40	57	3	C
Steubenville, OH	5S	7.26	1109	MA	3456	3.1	53	34	0	13	NG
Warren, OH	1	8.53	1530	PW	3153	2.1	11	83	0	6	NG
U. S. Steel											
Fairfield, AL	8	9.98	2326	PW	5380	2.3	91	0	0	9	C , NG
Gary, IN	4	8.80	1496	MA	3622	2.4	59	14	16	11	C
Gary, IN	6	8.53	1507	MA	3373	2.3	55	21	12	12	C , O
Gary, IN	8	8.53	1299		3154	2.4	57	23	6	14	C , NG
Gary, IN	14	11.96	3241	MA	8801	2.7	74	0	26	0	C
Granite City, IL	A	8.30	1435		2631	1.8	0	91	0	9	NG
Granite City, IL	B	8.30	1402	MA	3529	2.5	0	91	0	9	NG
Great Lakes, MI	B	8.61	1645		3745	2.3	0	93	0	7	C , NG
Great Lakes, MI	D	8.53	1508		3717	2.5	66	27	0	7	C , NG
Mon Valley, PA	1	8.78	1598	MA	3619	2.3	62	25	0	3	NG,COG
Mon Valley, PA	3	7.69	1381		2850	2.1	62	24	0	4	NG,COG

Legend: charging MA = movable armor, PW = bell=less injectants: C=coal, NG=nat. gas, O=oil, T=tar, COG=coke oven gas

2.3 Blast Furnace Facilities

The North American blast furnaces are a quite diverse group. Nearly 80% of the blast furnaces were constructed prior to 1975, and nearly 40% prior to 1950. Of the 21 production locations, 19 operated only one or, at most, two blast furnaces. Less than 20% are free-standing design, which means that 80% are of lintel design. Cooling systems are also diverse. 55% of the blast furnaces utilise plate cooling for the bosh, 35% use staves, and the remaining 10% utilise external cooling, either spray or jacket types. Stack cooling is nearly 80% by copper plates, with only 20% by staves. Although there have been many upgrades over the years, the plate cooler spacing is generally not robust, and water systems are limited, both in terms of quality of water available and water quality. All of this indicates a need for technology to sustain operation with limited downtime, partly due to economic considerations and partly due to attempts to avoid disruption of their individual customers in the event of sustained furnace downtime for reline. During the difficult decades of the 1980's and 1990's the major focus was on exactly those efforts(3,4) to:

- extend the campaign life of blast furnaces and/or
- selectively upgrade and modernize such furnaces.

The campaign life extension efforts encompassed both process and equipment related activities:

improving process stability - through consistent raw materials: higher quality coke, fluxed pellets and maintaining sinter percentage where possible, along with burden distribution control and distributed control systems

extending lining life – mainly through either remote repair techniques or interim repairs. The repair methods include gunniting and shotcreting (to be discussed later) and installation of supplemental cooling such as circular coolers.

With the above strategy, the furnace hearth life can become the limiting factor in determining furnace life. Here the North American blast furnaces have established global leadership through a combination of the following:

- widespread use of the North American (UCAR) small brick sidewall design (to be discussed later),
- use of high quality coke, made possible by excellent North American coals, to maintain hearth drainage and,
- selective use of ilmenite.

selective upgrading of furnaces - This has included widespread installation of burden distribution equipment (Paul Wurth bell-less tops or movable armor), upgrades of stack and bosh refractories and cooling systems (high density plate or staves: cast iron or copper. The casthouse area has also seen improved drills, mud guns, runner systems, tilting runners,

2.4 Blast Furnace Shotcreting

The lining, particularly of plate cooled, lintel design, blast furnaces, typical of North America, wears at an uneven rate during a blast furnace campaign. This type of wear creates a new geometric shape that is not as efficient as the original design. This results in higher reductant consumption and a corresponding drop in productivity. In past times the remedy for these wear mechanisms has been the rebricking or full reline of the blast furnace by conventional means, with an inherently high capital cost and lengthy outage duration, neither of which are appealing for today's one or two blast furnace plants. The timing of such a reline is normally governed by a failure that cannot be corrected during normal operation, or even a few days stop; this has usually meant the hearth. As previously stated, North American hearth lives are routinely greater than 20 years, which leaves some other zone of the furnace to dictate when rebricking is necessary, usually the bosh or stack. In former times, boshes and stacks were dry gunned, with generally unsatisfactory results, particularly in terms of the longevity of the repair. Three or four months were typical. However, around the year 2000 a new technique was developed. Shotcrete, or "spray gunned" materials, normally robotically applied, were developed to remove some of the inconsistencies of the dry gunned materials, i.e. dust generation and rebound during application, poor material mixing, laminations, and significantly improved strength. This technology has been improved with the development of patented colloidal silica bonded refractories, which use no water and contain no calcium aluminate cement (CAC). The actual technology is somewhat complex, but simply put this new technology permits more rapid installation with mimimal rebound, very rapid dryout times less than 50% of traditional methods, and greater lifetime for the refractory due to greater material strength due to the bonding strength of the material. By 2008, almost no CAC material is used any more. The process has been further refined until, today, a typical repair schedule involves one day each for preparation & blowdown and equipment installation & cleaning. The spraying of refractory takes up to 50 Hrs (500 tonnes applied at 10 tph) followed by one day for clean up & furnace re-start. This means that a blast furnace with a well-worn bosh and stack could be reprofiled back to its original design lines in about 5 days, from last cast until the first. Analysis has shown that such repairs have an effective life of more than 2 years. As reported earlier(6) by Magneco Metrel and AISI ironmakers, the reprofiling also contributes to a reductant savings as gas flows and utilization were improved. Over the limited time span of the year 2000 to present, 25 of the 36 operating blast furnaces in North America have been re-profiled in this way, with nearly 20,000 tonnes of refractory applied, while only 4 furnaces have been traditionally relined.

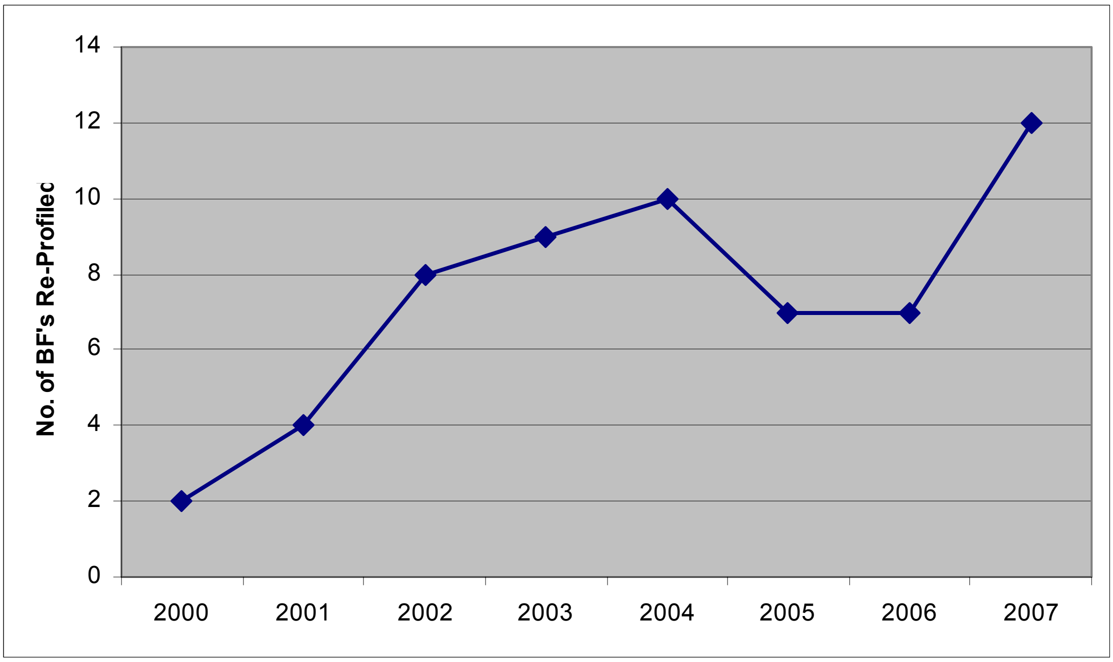

Figure 3: Number of North American BF's Re-profiled > 90 tonnes applied

The single negative of this reprofiling technology is the requirement to stop the blast furnace approximately every two years, which can have a serious and negative effect upon the lifetime of the hearth, and potentially undermine the goal of the Reprofiling effort, i.e. to extend the furnace campaign. Fortunately, North American hearth design and technology are compatible with the challenges thus offered.

2.5 Hearth Design

North American hearth design is fundamentally different from the so-called “big block” designs, more common elsewhere. In North America, UCAR Hot-Pressed ™ bricks are utilised, based upon the fundamental concept that the common causes of hearth wear – chemical attack, thermal stress, and erosion – all depend upon high temperature. The UCAR design uses a thin wall, small pieces, and expansion allowance to create and maintain an efficient thermal system. Temperatures are demonstrated to be low enough to freeze a stable protective skull, and thermal stress cracking and chemical attack are prevented. This concept is gaining much wider acceptance world-wide, and two direct comparison trials are underway; one at BaoSteel in PRC since 1993, and the other at Salzgitter in Germany. In published reports, both campaigns, which are continuing, the superiority of the thin wall, high conductivity concept is demonstrated.(7,8) Figure 4 shows the current lifetime of the North American hearths, as defined by the life of the furnace bottom.

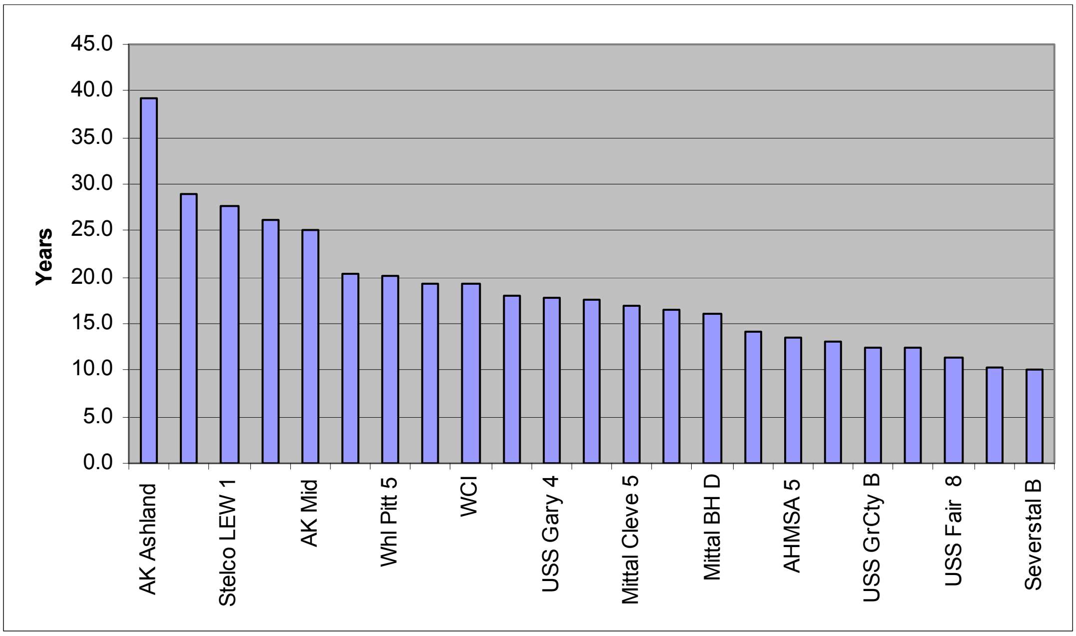

Figure 4: North American Hearth Bottom Lifetime

Of more importance is the lifetime of the sidewalls. This is shown in Figure 5, with the additional data point of the number of times the furnace was stopped, cooled, and at least some new refractory installed, most often a shotcrete reprofiling.

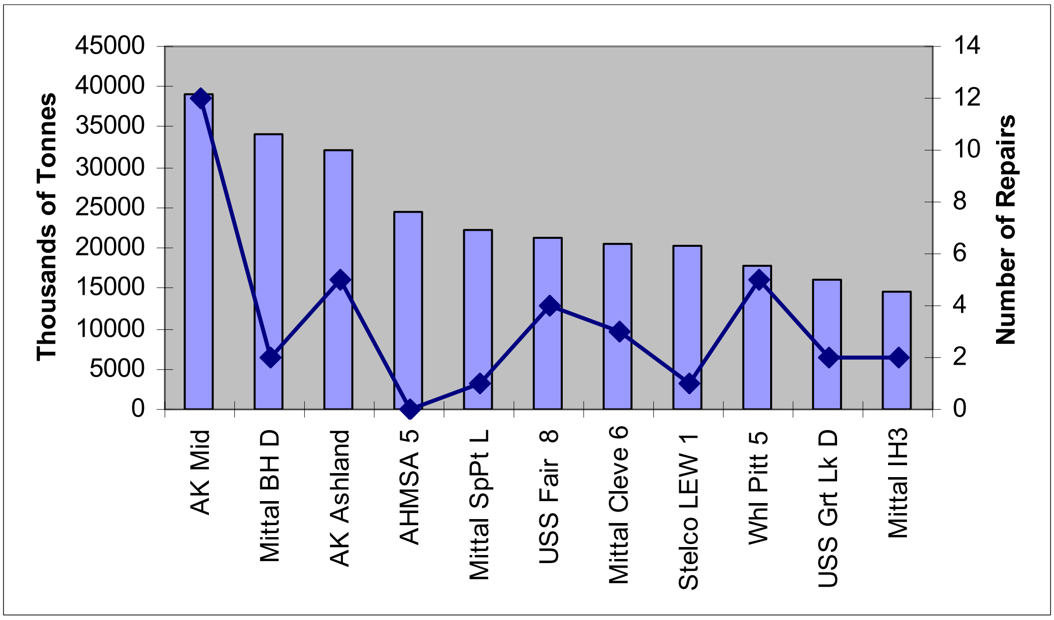

Figure 5: North American Hearth Sidewall Lifetime, and Number of Furnace Refractory Repairs

Of particular interest is the AK Middletown Blast Furnace 3, which is now at 25 years, nearly 40 Million tonnes, and differing from most furnaces at the end of their campaigns, remarkably continues to be the highest productivity blast furnace in the world at greater then 4.0 tHm/m3*24 Hrs for each of the last 5 years! In addition, this furnace was stopped for bosh and stack repairs 12 times by now, obviously with no observable negative effects. All of this using a hearth system which was designed for a five year lifetime. The graph also indicates a number of different furnace sizes and configurations, single and multiple tapholes, shower, stave, and channel cooling, and a range of wall and taphole abutment designs. The one thing that all do have in common, however, is that all use the UCAR thin wall concept with UCAR's Hot-Pressed^{TM} brick technology.

2.5 "New" Blast Furnace Construction

The improved economic outlook for North American blast furnace based has led to projects to completely rebuild a number of key blast furnaces in North America. These projects have included furnace enlargements, installation of bell-less tops (if not already available), copper and cast iron stave cooling, major casthouse (and stockhouse in some cases) renovations, new gas cleaning and water systems, new blowers, extensive instrumentation, and state of the art data acquisition and process control systems. Such major projects are summarized in Table 2.

Table 2: Major Blast Furnace Projects (Note: New AHMSA 6 replaces Old AHMSA 4)

		ArcelorMittal	ArcelorMittal	US Steel	Severstal	AHMSA	Severstal
		Indiana Harbor	Dofasco	Gary	Dearborn	Monclova	Dearborn
		7	2	14	C	6	B
Year		Oct 2002	July 2005	Jan 2006	Oct 2007	2009	2009
Hearth Diam							
Old	m	13.7	6.3	11.1	8.8	7.5	6.1
New	m	13.7	7.3	12.0	9.2	8.5	7.2
Working Volume							
Old	m³	3739	923	2955	1506	1034	794
New	m³	4163	1062	3241	1798	1150	920
No. of Tuyeres							
Old		40	12	35	20	19	12
New		40	15	34	20	22	16
Hot Blast Temp							
Old	˚C	1200	1000	1150	980	1150	1000
New	˚C	1270	1100	1200	1065	1150	1000
Production							
Old	tHM/d	9700	2400	7500	4900	3500	2500
New	tHM/d	11200	3000	9200	5900	4700	2625
Other							
Cu, Fe Staves		→	→	→	→	Hi Dens Plates	
Add Bell-less Top				→	→	→	
Add PCI					→		
2nd Taphole					→	→	

The capital costs for the above projects ranged from 200 to 400 million dollars and underscore the commitment of North American ironmaking to the future.

All of the blast furnace projects (except AHMSA in 2009) listed in Table 2 are operational in 2008 while the following additional projects are proceeding:

- Restart of ArcelorMittal Dofasco BF 3 (hearth diameter, 7.3 m); this furnace will supply hot metal to both the KOBM and the EAF shops,
- Restart of Essar Steel Algoma BF 6 (hearth diameter, 8.2 m)

Nucor blast furnace project - The most exciting new project being planned is the Nucor Steel greenfield blast furnace project in St. James Parish, Louisiana, located on the Mississippi River. This would be the first greenfield blast furnace facility built in the US in over 30 years. The 3 million net ton-per-year facility would include a sinter plant, blast furnace and pig casting machines (or iron granulation facilities), owned and operated by Nucor while Sun Coke would own and operate a coke plant based on heat-recovery coke technology. The single large blast furnace (contract awarded to Danieli Corus) would use the latest technology in emissions controls and energy efficiency and also includes slag granulation technology, The plant layout would include provision for expansion to double or triple in size while the permit application also mentions an eventual BOF/slab caster facility, as well. The initial objective is to produce pig iron for shipment to Nucor's EAF plants.

2.6 Blast Furnace Raw Materials

New cokemaking capacity – The explosive increase in the prices of imported (mainly Chinese) coke in 2003/2004 exposed the danger of reliance upon outside coke sources. Fortunately this occurred in the current period of renewed ironmaking optimism. The response included the construction of a completely new coke plant, the Sun Coke (with off-take guarantee by ISG -now ArcelorMittal) Haverhill heat recovery coke plant. This followed the start-up in 1998 of the first heat recovery coke plant in North America, also by Sun Coke, at the site of the former Inland Steel (now Mittal Steel Indiana Harbor East) plant. The success at Indiana Harbor and Haverhill spurred a number of other heat recovery coke plant projects in the USA; Haverhill II (offtake to Severstal), USSteel Granite City, AK Middletown (all will proceed) while other projects are under study: Haverhill III, Sparrows Point and Toledo, as well as the Nucor Louisiana plant mentioned earlier. In addition to heat recovery cokemaking, plans to rebuild several conventional slot oven coke batteries are proceeding; these include Mountain States Carbon, a JV of SeverstalNA and Wheeling-Pitt, and battery rebuilds at USS Clairton. USSteel is further proceeding with a 0.20 MTPY formed coke plant near Fairfield, Alabama based on the novel Carbonyx technology

Coal Injection Facilities – as noted above, the decline of coke oven capacity was partially relieved by adoption of coal injection at major plants, as listed in Table 1. It was expected that the sharp increases in imported coke prices would have spurred coal injection projects at many of the remaining blast furnace sites in North America. In fact, the rebuild of SeverstalNA BF C with PCI is the only new PCI project in this decade! The reasons why include the following: local availability and cost of other injectants (natural gas, oil, etc), beneficial impact on productivity of natural gas and selective use of other carbon bearing materials, these include lump anthracite coal, waste oxide briquettes featuring coke breeze. Furthermore, there was lingering uncertainty about the future of some of the smaller blast furnace operations.

The use of other injectants has been part of an expanding “co-injection” philosophy where multiple injectants are used on the same furnace with the common motivation to replace as much coke as possible. Several specific practices can be sited:

- Supplementing PCI/GCI with gas or other injectants to avoid the problems inherent in maximizing PCI/GCI rates beyond 150 – 160 kg/T, as well as replacing blast moisture. The high H2 content of natural gas is important here.
- For furnaces without coal injection, the limitations of supply or system capability with any one injection are extended with multiple injectants.

A summary of North American co-injection is presented(2) below:

	Nat Gas Only	Coal Only	Coal + NG	Coal + Tar	NG + Oil	Oil	NG + Tar	COG + NG
Number of BF's	5	2	18	2	7	1	1	2

North American coal injection practice (ArcelorMittal Burns Harbor, USSteel Gary) features use of higher rank coals that replace more coke while some operations like Severstal Sparrows Point use a blend of high and low volatile coals.

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. Increased utilization of nut coke has also been important. A summary of North American progress updated from our earlier ABM paper(1) is presented below:

Table 3: Weighted (by Production Rate) Averages of Reductants by AISI(4) BF's

Year	Hot Metal Production	# of Operating	Reductant Consumption, kg/tHM							
			Coke			Injectants				
	M Tonnes	BF's	Lump	Nut	Total	Coal	Oil	Gas	Tar	COG
1990	55.5	60	454	1	455	1	12	23	3	0
1995	61.0	51	402	8	410	34	13	38	1	1
2001	51.9	45	395	24	419	59	9	17	3	2
2004	52.7	38	366	26	392	58	10	35	4	2
2007	47.8	35	377	28	405	65	9	27	2	2

Some levelling off in progress is apparent; the growth of coal injection has been hampered by both lack of new facilities and coal availability to optimize performance of existing coal injection facilities. Fortunately, new PCI facilities are forthcoming: a PCI plant started up this year at SeverstalNA while a PCI plant is under construction at ArcelorMittal Dofasco and PCI project planning is advanced at a number of other plants including a regional coal prep facility in the Ohio area. USS Fairfield has also installed on-site coal grinding facilities to enhance use of the existing GCI equipment on BF 8.

Ferrous Raw materials – Pellets comprise about 90 % of the blast furnace feed in North America. The all-pellet operations focus on fluxed pellet usage but acid pellets are prominent as a complement to sinter and also at several operations where hot metal demand can be met with acid pellet usage. The all-pellet operations charge between 5 – 10 % BOF slag, reclaimed scrap, pellet chips, and waste oxide briquettes. The latter at produced on-site by third party companies at 6 plant sites. These briquettes, lacking in high temperature properties, can be used up to 5 % of the blast furnace burden. For sinter feed, AHMSA relies on local ores while Sp. Pt. uses mainly Brazilian ores; the remaining sinter plants recycle reverts materials for more than 50 % of their sinter feed along with Brazilian ore and Canadian concentrates including those of ArcelorMittal Mines Canada. The revert materials include pellet screenings, mill scale, breeze, BOF slag, dusts and sludges.

The very high productivity AK Steel Middletown BF 3 operation is a special situation where an ongoing hot metal shortage is met with use of over 200 kg/T of HBI along with some prepared scrap. Several other operations use lesser amounts of HBI during periods of peak hot metal demand or to cover the reline outage of another blast furnace.

Overall raw material ownership – as outlined earlier, the dramatic increase in both the cost of raw materials and ocean freight has provided an overall competitive advantage to North American ironmakers. An outline of North American pellets plants is presented in Table 4:

Table 4: North American Pellet Plant Capacity and Ownership

Plant	Annual Capacity	Ownership, %				
	MT	US Steel	Cliffs	ArcelorMittal	Ternium	AHMSA
Minntac	14.5	100				
Keetac	6.0	100				
Minorca	2.8			100		
Hibbing	8.0	15	23	62		
UTAC (1)	5.0		70			
Northshore	5.2		100			
Empire	6.0		79	21		
Tilden	8.0	15	85			
AMMICA	9.2			100		
Wabush	6.0	45	27	28		
IOC (2)	12.5					
AHMSA	3.0					100
Pena Colarada	4.0			50	50	
Lazaro Cardenas DR	3.5			100		
Lazaro Cardenas BF	2.1			100		
Las Encinas	3.5				100	
(1) 30% Laiwu Steel (2) Rio Tinto 59%, Mitsubishi 26%, LOF 15%						

Within the ranks of these ironmakers there are considerable differences in ownership positions, as noted above, and therefore competitive cost structures. USSteel is most favored with the ability to meet 100 % of its pellet needs and nearly 100 % of its coke needs from captive facilities and with only one plant not having either coal injection or COG injection facilities. AHMSA also has nearly 100 % self-sufficiency. ArcelorMittal also has a strong iron ore, coke and injectant position. AK Steel, Essar Steel Algoma, and Wheeling-Pitt have strong coke positions; these companies along with SeverstalNA have, stable long term pellet supply relationships (but at market prices) with leading pellet suppliers: Cliffs, AMMICA, IOC and VALE.

The North American steel companies are further solidifying their strong raw material position with the following projects:

Keetac – restoring production at Line 1 to increase production by 3 MTPY

Minnesota Steel (Essar) - restoring the former Butler mine, concentrator and pellet plant facilities to produce 3 – 4 MTPY (eventually DR grade to feed a new steel plant based on DRI/EAF production) but immediately to supply Algoma

Northshore – expanding pellet production by 0.6 to 0.8 MTPY.

AM Lazaro Cardenas – developing (> 2 MTPY) the Volcan mine to feed the DR pellet plant,

SDI – restarting a portion of the former Erie (LTV Steel) Mining Hoyt Lakes mine and concentrator to feed their Mesabi Nugget plant currently under construction (see below).

Expansion projects are under study at IOC and AMMICA while a number of greenfield mine/concentrator/pellet plant projects are being proposed in Canada. All of the latter face major obstacles starting with infrastructure (rail, port) requirements. Another project, Baffinland Iron Ore Mines, to mine and ship magnetite lump and fine ore, has a good chance of advancing but mainly to supply the European market.

We have presented an overview of North American ironmaking; we now provide further details on oxygen enrichment.

2.5 Blast Furnace Oxygen Use

Oxygen costs are generally lower in North America due to lower energy costs. Also, industrial gas suppliers have reduced oxygen costs with installation of large on-site oxygen plants (including some onsite reduced purity oxygen plants) and very large off-site plants connected by pipelines to multiple steel works. The injection of coal (and natural gas, simultaneously in many cases) have motivated high levels of oxygen enrichment, which in turn helps to improve furnace productivity. From 1990 to 2005, oxygen consumption increased from about 2000 m³/hr to about 14000 m³/hr

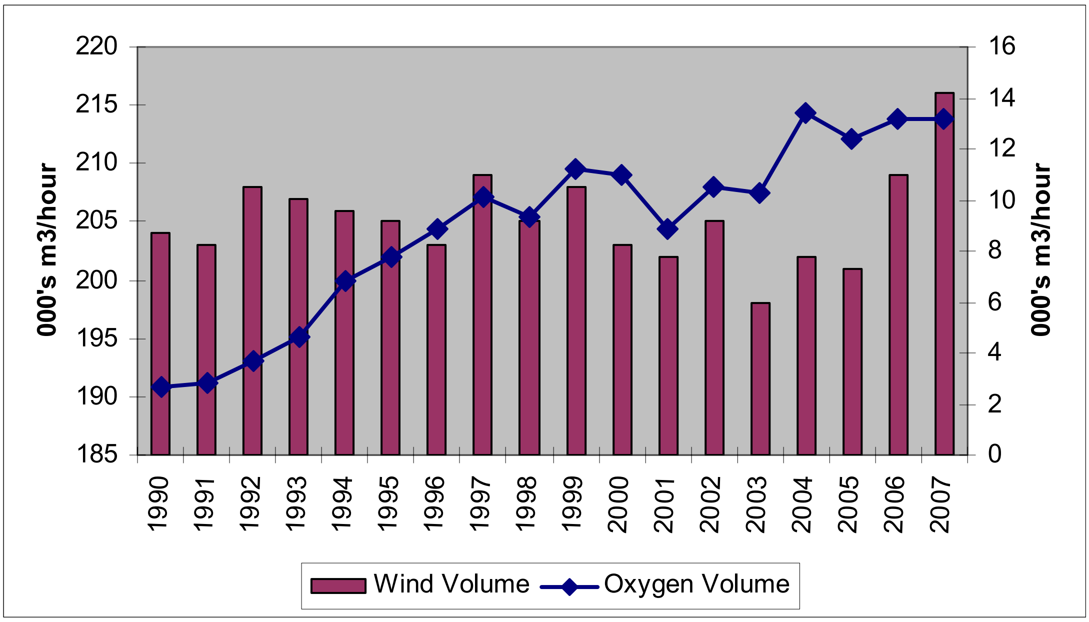

Figure 6: Consumption of Oxygen, Wind by North American Blast furnaces.

3 UPDATE ON ALTERNATIVE IRONMAKING

3.1 Role of Alternative Ironmaking in North America

Alternative ironmaking is aimed mainly at the supply of virgin iron units as feed materials for the electric arc furnace (EAF) particularly for flat-rolled steel production. Another application of alternative ironmaking is waste oxide processing but so far several rotary hearth furnace (RHF) DRI plants have been built in North America; all are idle at present. The only operational waste oxide processes, besides sinter plants, are the briquetting plants mentioned earlier, but these are not reduction processes but only providers of blast furnace or BOF feed material.

We will discuss metallic sources for the EAF.

3.2 Direct Reduction Processes

The shaft furnace gas based direct reduction processes (Midrex, HyL) are prominent while the fines based, gas based processes are no longer receiving any attention. Natural gas pricing is a major problem for the MIDREX and HyL processes in North America. 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.

North American DRI production is about 5 MTPY, with over 4.0 MTPY of this in Mexico; all of these provide DRI to EAF's in captive steel plant settings. Ternium (ex-HylsaMex) operates HyL plants at two sites in Mexico, Monterey and Puebla, while ArcelorMittal operates both HyL and Midrex plants at Lazaro Cardenas in Mexico and Midrex Plants at ArcelorMittal Canada.

The leading shaft furnace processes, Midrex and HyL (now called EnergIron) were developed in North America and the engineering companies offering these processes and their customers have contributed to ongoing technical developments that have increased productivity, decreased energy consumption and improved product quality in an evolutionary manner similar to that already outlined for the blast furnace process.

3.3 Alternative Hot Metal, Pig Iron Processes

In Mexico, with reasonable natural gas prices, we expect continued use of HyL or Midrex processes. However, in the USA and Canada the focus of new process development has been on coal based processes such as Iron Dynamics, Inc (IDI) and ITmk3 (Mesabi Nugget).

The Steel Dynamics IDI (Butler, Indiana) hot metal process has been modified to produce briquettes of iron ore concentrate, coal, mill scale, and other waste oxides; these briquettes are then be reduced in a rotary hearth furnace (RHF). The DRI produced is then melted in a submerged arc furnace to produce liquid hot metal for EAF charging. Further process development will be aimed at reaching the earlier design production rate of > 35,000 tons/month.

Another promising development is the Mesabi Nugget (ITMk3 process) RHF process that uses iron ore fines, mainly pellet plant feed, coal, binders, etc. A demonstration plant for the ITMk3 process produced pig iron nuggets that have been used in SDI's EAF's in Butler, Indiana. Two 0.5 MTPY Mesabi Nugget plants are planned: an SDI/Kobe Steel JV in Minnesota and a Cliffs/Kobe Steel project at the Empire mine in Michigan.

Nucor Steel, the largest EAF based steel producer in North America, is involved in three offshore metallics projects, as well as the blast furnace project discussed earlier

HIsmelt plant - Nucor is a partner (along with Rio Tinto, Mitsubishi, Shougang) in the 0.8 MTPY HIsmelt pig iron plant in Australia. This plant started up several years ago; it operates at about 80 % capacity. A successful project here could lead to such plants being built in the USA to provide hot metal to Nucor's EAF's.

Brazil pig iron plant - A Nucor/CVRD JV built and operated a 0.5 MTPY mini-blast furnace plant in the Carajas region of Brazil to produce pig iron for its EAF's in the USA. VALE (formerly CVRD) is now the sole owner with Nucor as the sole off-taker.

Trinidad Midrex plant - Nucor is operating Nu-Iron in Trinidad with the relocated AIR Midrex MegaMod plant; production could exceed 2 MTPY of DRI, all shipped to Nucor's EAF's in the USA.

Nucor is believed to be also conducting research on its own variant of a pig iron nugget process.

In summary, the two leading EAF flat-rolled steel producers, Nucor and SDI, are pursuing multiple projects to own and operate metallics producing facilities in order to minimize the purchase of such metallics and premium scrap. The success of these projects will improve the EAF cost position relative to the blast furnace based steelmakers. Other EAF based steel companies are buying scrap companies while others continue to rely upon the merchant metallics market.

5 CONCLUSION

The competitive position of the blast furnace based steelmakers in North America has dramatically improved due to consolidation, cost reduction, global economic trends, a favorable raw material cost position, freight advantages, currency shifts, etc. However, technological developments have also contributed to the resurgence of the North American blast furnace based steel sector:

- **Breakthroughs in heat recovery cokemaking technology**, allowing the first new coke battery construction in North America in many years,
- **Continued technical improvement in blast furnace performance**; productivity and reductant rate due to enhanced raw materials, facilities and process control; the facility improvements include new blast furnaces and upgrades of existing furnaces.
- **Leadership in the "endless campaign" technique** with improved shotcreting and taphole repair methods; along with continued excellence in hearth life design, refractory selection and maintenance.

While the blast furnace based sector is now well positioned for the intermediate term, the leading EAF mini-mill companies continue to aggressively pursue alternative iron projects to strengthen their metallics position.

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