ISSN 2176-3135

ICSTI
6th International Congress on the Science and Technology of Ironmaking - ICSTI
42nd Ironmaking and Raw Materials Seminar/ 42º Seminário de Redução de Minério de Ferro e Matérias-primas
13th Brazilian Symposium on Iron Ore/ 13º Seminário Brasileiro de Minério de Ferro

PROSPECTIVE OF TITANIA- MAGNETITE ORE PROCESSING IN BLAST FURNACE AND ALTERNATIVE IRONMAKING[1]

Yakov Gordon[2]
Michiel Freislich[3]
Harry Brunger[3]
Peter Slack[3]
Leigh Harris[3]

Abstract

Titania-magnetite ores represent a largely untapped resource for international steelmakers in spite of representing a significant percentage of the Earth's available iron. Recent developments in titania–magnetite ore processing technologies have made them economically viable. This paper explores maturity of titania-magnetite blast furnace, rotary hearth furnace in combination with smelter and ITmk, their basis of operation, comparative cost position and viability under the following site specific conditions: For large installations able to source coking coal at reasonable cost; For mini-mills favored by low cost natural gas and power. The analysis shows that the selection of the appropriate technology depends on local cost factors and steel demand. For large installations able to source coking coal at reasonable cost, the Ti BF with maximum TiO2 load of about 50-60 kg/thm should be considered as the technology of choice. However, for mini-mills favored by low cost natural gas and power the RHF + Smelter process will be a suitable alternative. If the Itmk3 is successful, it will represent a breakthrough as it will allow for the wide use of Ti bearing ores in EAF steelmaking.

Key words: Titania-magnetite ore; Blast furnace; Rotary hearth; ITmk3 process.

---

[1] *Technical contribution to the 6th International Congress on the Science and Technology of Ironmaking – ICSTI, 42nd International Meeting on Ironmaking and 13th International Symposium on Iron Ore, October 14th to 18th, 2012, Rio de Janeiro, RJ, Brazil.*

[2] *Hatch. Mississauga, Ontario, Canada*

[3] *Hatch. Wollongong, NSW, Australia*

1 INTRODUCTION

Titania-magnetite (TiMag) ores represent a largely untapped resource for international steelmakers in spite of representing a significant percentage of the Earth's available iron. Present in many areas as beach sand but also lumpy magnetite, it contains 7-14% TiO2 and often economically recoverable amounts of vanadium. Unfortunately TiO2 has always proved difficult to handle in Blast Furnaces in concentrations above 10 kg/thm, due to dramatic increase of slag fluidity because of formation of TiC and TiN in the blast furnace hearth. TiO2 also acts aggressively in steelmaking slags to increase refractory wear.

As a result steel companies have to a limited extent developed an alternative approach of using rotary kilns combined with smelters to produce liquid iron suitable and low titania slag. However, this technology is hampered by scaling constraints and high fuel rates.

- Recent developments have made the processing of these deposits potentially economically viable;
- Development of TiBF technology in Russia and China matured to the extent that fuel rates and in some cases productivity achieved levels comparable to commercial blast furnaces
- Increase in size of smelters, combined with improved design and scale of Rotary Hearth Furnaces (RHF's) have improved the viability for the RHF+Smelter routes

Development of the Itmk3 process and its suitability for the processing of TiMag ores, have opened up an exciting possibility for processing TiMag ores for EAF input.

This paper explores how these technologies have matured, their basis of operation, comparative cost position and viability under the following site specific conditions;

- For large installations able to source coking coal at reasonable cost
- For mini-mills favoured by low cost natural gas and power

Each of these process routes are faced with significant obstacles. The Ti BF route productivity and blast furnace life is largely lagging behind commercial blast furnaces. Although improved furnace designs have mitigated this problem, the principles underlying improved furnace designs are not universally understood.

At the same time Rotary Hearth Furnace technology (RHF) still faces significant scale up risks as the largest plants have not surpassed 0.35 ktpa production level.

The ITmk3 technology has only recently matured to commercial status. The first operating unit at Mesabi experienced commissioning problems and delays and has at yet, not attained its rated capacity. the process offers significant opportunities due to its low fuel rate, ability to deal with fines, and suitability of nugget as input feed to EAF's. When used for TiMag ores the partition of TiO2 to the slag phase is an added benefit as it reduces the need for a smelting step to reduce Ti to a level suitable for steelmaking.

The analysis shows that the selection of the appropriate technology depends on locational cost factors and steel demand. For large installations able to source coking coal at reasonable cost, the Ti BF with maximum TiO2 load of about 50-60 kg/thm should be considered as the technology of choice. However, for mini-mills favoured by low cost natural gas and power the RHF+Smelter process will be a suitable alternative. If the Itmk3 is successful, it will represent a breakthrough as it will allow for the wide use of Ti bearing ores in EAF steelmaking.

2 BACKGROUND

The conventional blast furnace remains the mainstay of iron and steelmaking throughout the world, due to its high efficiency, technological maturity and low conversion cost. However, input materials such as good grade iron ore and metallurgical coke are deteriorating in quality and increasing in price. This results in large increases in the product cost, and shrinking margins for steel companies.

The alternative to the conventional blast furnace, the DRI>EAF route, is beset by its own problems. Higher energy prices notably power, and in some areas natural gas, has reduced its comparable advantage while it also needs good grades of iron ore.

Other alternative ironmaking technologies that have achieved industrial application, such as Rotary Kilns and the Corex process have had limited application due to high coal rates and in the case of the kiln, low productivity. As a result, their use has been limited to niche market players. New Zealand Steel, for instance, operates 4 multiple hearth furnace/rotary kiln streams in combination with 2 electric smelters to produce about 700 000tpa hot metal from titanomagnetite iron sands and sub-bituminous coal.

The chemical composition of Titania-magnetite concentrates currently processed by various steel plant around the globe is presented in Table 1.

Table 1: Sample Of Ti Bearing Commercial Iron Concentrates

Commercial Iron Ore	Fet,%	TiO2,%	V2O5,%	MnO,%	S,%	%Cu	P,%
Panzhihua (Chinese)	51.56	12.73	0.546	0.33	0.532	None	0.045
Kachkanar Ore - NTMK	63	3.6	0.6	0.19	0.1	None	0.02
Mapochs Ore - Highveld	53-57	12-15	1.4-1.9	No Data	No Data	None	No Data
NZS	59-60	7.88	0.49	0.63	No Data	None	0.036
Chende (Study)	63	4.0	0.6	0.19	0.1	0.05	0.08

Lately, the development of the Titanium-Magnetite processing Blast Furnace (TiBF), has gained momentum and wider industry application (See Figure 1). In addition, technological developments in Rotary Hearth Ironmaking, as well as the advent of the ITmk3 process, have opened up opportunities to use Ti bearing ores as basis for commercial iron and steelmaking.

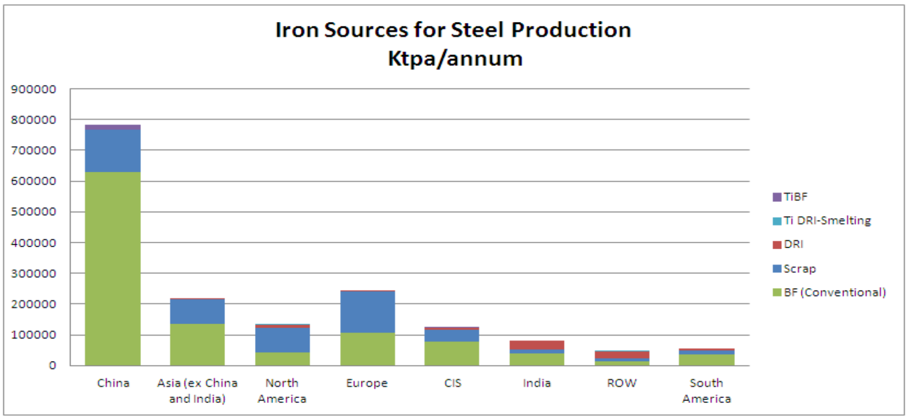

Figure 1: Application of Ironmaking Technologies

3 CASE FOR CHANGE

The business environment and technological advances now present a clear case for change. Firstly, increases in input prices such as iron ore and coking coal, have caused significant increases in input costs to steelmakers. In addition the grade of lump ores have declined and impurity contents of conventional ores are rising.

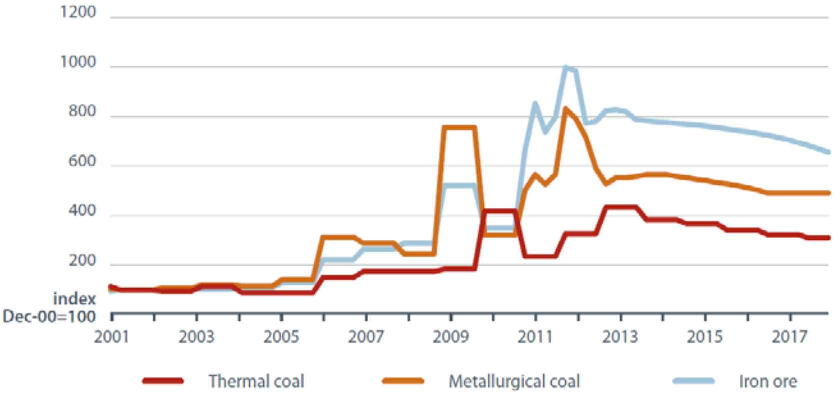

Figure 2: Raw Material Pricing Trends and Outlook – Australian FOB, source: BREE.

On the other hand the technology developments have now provided a means to process Ti bearing ores in economically feasible manner. The notable technological developments are;

- TiBF has been developed to a significant extent in Russia and China, through specialised Blast Furnace Operators.
- The Itmk3 technology may hold significant benefits as it overcomes many of the problems that the TiBF and the shaft furnace –EAF routes experiences, by the combination of indirect reduction at high reduction temperatures, and chemical based smelting –reduction.
- The Rotary Hearth Smelter route has also seen improvement. Capacities have increased with 500 ktpa or higher now possible. When combined with modern high power density smelting technology the ability now exists to generate pig iron from high TiO2 based raw materials.

Other processing technologies have also made progress, but have not fully gained a foothold on conventional iron ores, and may also present a high operational risk to Ti bearing ore processing.

The Corex / Finex combinations have been commercialised but not on TiMag ores. In addition, they show high fuel rates if PCI injection is not utilised. The injection of PCI and high Oxygen may cause problems with TiC and TiN formation, which will have to be overcome.

4 HIGH LEVEL COMPARISON OF THREE (3) PROPOSED TITANOMAGNETITE PROCESSING ROUTES

The three routes proposed for the processing of TiMag ores into liquid steel are depicted below. From the diagram it is evident that the ironmaking technology has different possible applications. The TiBF and RHF+Smelter are ideally linked to a BOS steelmaking step, while the Itmk3 is ideal for an EAF step, as it produces a low gangue nugget which is easily smelted. It is also readily apparent that the Itmk3 – EAF route is elegant with the least process steps, but this doesn't account for the higher productivity and efficiency of scale of the TiBF route, as well as the possibility of erosion due to TiO2-containing slag in the EAF.

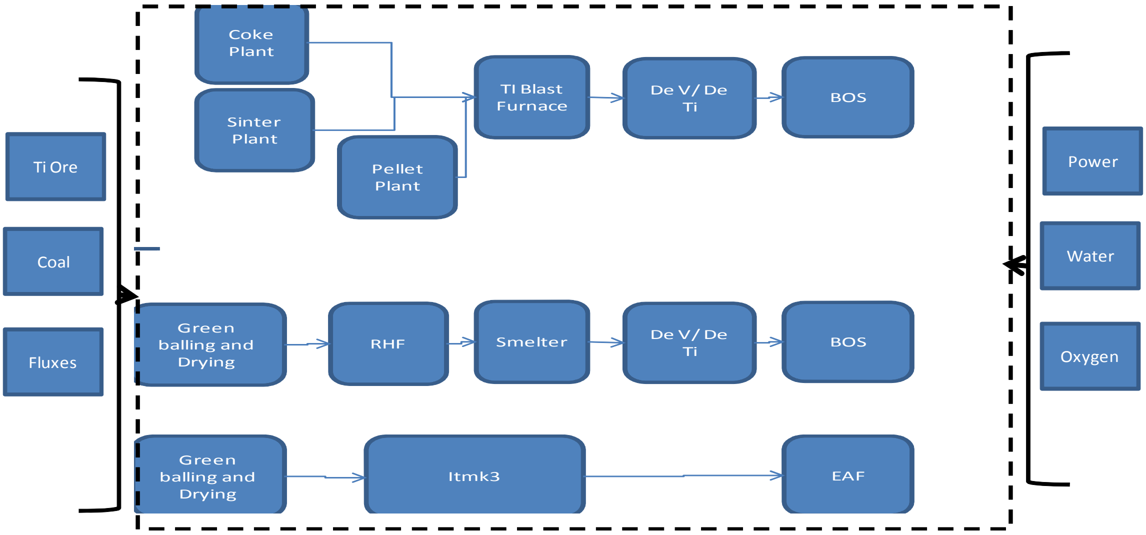

Figure 3: Block Diagrams of Possible Ti Treating Flowsheets Showing Battery Limits.

The routes also have different risks, advantages and disadvantages to the steelmaker. This makes each route suitable for particular site specific conditions due to the combined impact of capital, utility costs and capacity requirements.

	Advantages	Disadvantages
TiBF + BOS	Economy of scale > 1.5 Mtpa possible Mature technology	Risk of TiC and TiN formation controlled by specialised low Si practice Need high % of prepared burden Need high CSR coke
ItMk3+ EAF	Low Capex cost Modular units No need of coking coal High productivity	Recently commercialised , not well proven Need for fuel gas, preferably NG
RHF + Smelter + BOS	Proven on waste and low quality iron bearing ores Robust technology and flexible Good quality pig iron Useful for high TiO2 raw materials and lower	High power requirements for Smelter Low productivity at high metallisation

reducibility materials

5 DEVELOPMENT OF THE TI-BLAST FURNACE

In conventional Blast Furnace ironmaking the TiO_2 is limited to < 10 kg/ thm. Beyond this TiO_2 content the Blast Furnace is susceptible to;

- Formation of accretions from titanium carbides (TiC) and titanium nitrides (TiN) and increase in melt viscosity are disastrous for blast furnace performance
- Damage to tuyeres, and
- Reduction in furnace productivity and stability, up to a point of inoperability

The formation of TiC and TiN follows a complex reaction chain occurring in various zones of the Blast Furnace;

$SiO_2 + C = SiO + CO$	eq 1. (at tuyere)
$SiO + TiO_2 = [Ti] + SiO_2$	eq 2. (reduction of TiO_2 in cohesive zone)
$[Ti] + [C] = [TiC]$	eq 3. In active zone and hearth
$[Ti]_m + [N] = [TiN]$	eq 4 In active zone and hearth

Once TiC and TiN is formed in the active zone of the blast furnace, the primary and secondary slag viscosity increases dramatically, which causes slag hold-up in the furnace. As a consequence productivity decreases due to increased pressure loss in the furnace, compelling a reduction in blast volume. TiBF operators developed specialized practices to overcome these problems.

Control TiC and TiN formation with minor losses in Blast Furnace productivity	BF operational adjustments to process titano-magnetites without losses in Blast Furnace performance
• Maintain stability of the raw materials and heat conditions of the furnace • Utilise burden with maximum titania load of 50 kg TiO_2 /thm • Operate at maximum possible pressure to suppress reduction of Si and Ti and formation of titanium carbides • Moderate the thermal level of the blast furnace hearth with RAFT in the range of 1850 - $2000^{o}C$ • Lowering the hot metal tap temperature to 1430 ± $20^{o}C$ • Maintain slag basicity in the range of 1.15 - 1.25 • Regular and complete tapping of hot metal and slag to avoid titanium carbide formation • Introduce manganese sinter or ore into the burden to destroy titanium carbides and increase slag fluidity	• Charge small size (25 - 40mm) and large size (40 - 80mm) coke separately to increase permeability of the hearth • Operate blast furnace with coke strength after reaction (CSR) above 58 • Implement high prepared burden to reduce cohesive zone thickness and enable low Si practices • Reduce basicity of the slag to 0.8 - 1 (if vanadium recovery is not important) to improve slag fluidity. This will, however, negatively affect the content of S, Si and Ti in the hot metal • Operate blast furnace with increased oxygen content and supplemental fuel, to increase BF productivity maintaining the optimum RAFT and reducing nitrogen input with blast (to reduce nitrogen partial pressure and to minimize titanium nitrides formation) • Build (or rebuild) the blast furnace with optimum useful volume of 2,200 m^3 • Provide a hearth height to hearth diameter ratio of close to 0.47 • Increase the blast pressure to 0.4 MPa gauge or more to suppress formation of SiO gas and hence reduction to Si and Ti and formation of titanium carbides • Equip the blast furnace with all the modern features, bell-less top, copper plate or copper staves cooling

system, high temperature stoves, modern control systems

-

Using these designs TiBF operators can maintain good low quality Si hot metal; however, as most BF operators view the TiBF practice as risky they have not implemented this practice widely. Typical blend compositions for specific ores are specified in the Table 0 1. In addition a scenario for a hypothetical ore and blend is defined for simulation purposes.

Table 2: Burden Compositions For Ti Bearing Plants, and for Hypothetical Study Plant

Chemical composition, %									
BF Burden	Fe Total	SiO2	Al2O3	TiO2	V2O5	CaO	MgO	MnO	Total TiO2 burden, TiO2 load, kg/thm
Plant 1									
BF burden	46.8	7.22	4.3	8.26	0.33	9.39	3.57		2060/170
Plant 2									
BF burden	54.78	5.48	3.36	2.25	0.45	7.33	2.46	0.21	1700/40
Study									
Sinter (70%)	52.15	4.72	2.81	4.5	0.255	8.73	3.1	0.9	
Pellet (30%)	64.72	2.41	0.64	0	0	2.60	0	0	
Burden	55.91	4.03	2.16	3.1	0.18	6.89	2.2	0.62	

All of this enables the BF to run stably and produce consistently acceptable hot metal, with acceptable consumption numbers for oxygen, and good fuel rates-see Table 0 2. The analysis of the hypothetical study plant was analysed using the Hatch TiBF Blast Furnace model. This model calculates the Mass and Energy Balance of the Blast Furnace, and evaluates the productivity impacts of an ore based on reducibility, and physio-chemical properties of the burden. This includes an assessment of the blast furnace flooding parameters and burden permeability.

Table 3: Hot Metal Analysis From Tibf Plants And For Hypothetically Modelled Study

Parameter	Unit	Conventional (Blast Furnace)	Plant 1	Plant 2	Study
Carbon	%	4.78	3.8-4.2	4.4-4.6	4.50
Silicon	%	0.32	0.4	0.18-0.25	0.08
Titanium	%	<0.05	0.12-0.16	0.21-0.28	0.12
Vanadium	%	<0.01	0.2-0.3	0.44-0.46	0.16
Manganese	%	0.33	0.1	0.3-0.33	0.53
Sulphur	%	0.025		0.033	0.1

Based on the model results, Hatch estimated the productivity parameters and consumption numbers of the TiBF based on the hypothetical burden results.

Parameter	Unit	Conventional (Blast Furnace)	Plant 1	Plant 2	Study
Titania load	Kg/thm	<10	114	40-50	52.5
Blast temperature	Deg C	1220	<1000	1200	1213
Top Pressure	Bar	2.2	1.0	2.7	2.24
BF inner volume	m3	4747	1350	2200	2200
Productivity,	thm/m3/day (WV)	2.7	2.1	3.6	3.6
Coke rate	kg/thm	269	550	395	372
PCI rate	kg/thm	228	120-130		0
Natural gas rate	Nm3/thm			121	0
Slag volume	kg/thm	257	720	360	360

From plant data, and the calibrated Hatch model it is clear that the TiBF has advanced in regards to fuel rates and productivity parameters.

- TiMag Blast furnace working volumes have increased greatly and are now approaching conventional capacity,
- Productivity parameters have improved, and are now similar to conventional blast furnaces if TiO2 contents are maintained < 50 kg/thm
- Fuel rates have improved markedly, notably due to furnace stability, highly prepared burden, and high PCI injection

6 APPLICATION OF ROTARY HEARTH FURNACES TO TITANOMAGNETITE PROCESSING

The development of the Rotary Hearth furnace has had several advantages for TiMag processing, when compared to Rotary Kilns. The Rotary Hearth is able to produce at higher capacities and lower fuel rates. In addition the process is environmentally more friendly. When used in combination with a modern high capacity smelter using electrical power, the process has the ability to produce cost competitive steel.

The process is depicted in Figure 4. The Rotary Hearth process requires a composite pellet which is made by grinding coal and ore concentrate to >800 blane. This is followed by green balling and subsequent drying to achieve the desired green ball strength by process heat. The composite pellet contains all of the carbon required for reduction in the RHF, but not for the smelter stage reduction and hot metal carburisation. Additional carbon for the smelter process could be obtained by adding anthracitic coal to the RHF floor where it is heated and charred.

When processing TiMagnetites the reduction process in the RHF can potentially slow down, due to the presence of Ulvospinels in the ore. These spinels are difficult to reduce below 1000oC and as a result the RHF retention time must increase to compensate by allowing sufficient exposure to high temperature zones in the RHF. Even then a significant portion of Ulvospinel reduction will not occur, and >80% of Ulvopspinel reduction may take place in the Smelter which increases power consumption. Since a higher degree of metallisation is associated with longer retention times and hence higher process fuel consumption per tonne of product and lower RHF productivity, maintaining the level of metallisation in the presence of ulvospinels can slow down the process and increase the fuel rate.

After reduction, the DRI and charred coal are transferred hot to a Smelter where the iron oxide undergoes direct reduction with the carbon in char producing metallic iron and CO gas. Additional calcined fluxes are added to the output of the RHF to ensure that the desired smelter slag chemistry is achieved. The smelter technology of choice is an open –bath smelter, which ensures high productivity through high power densities.

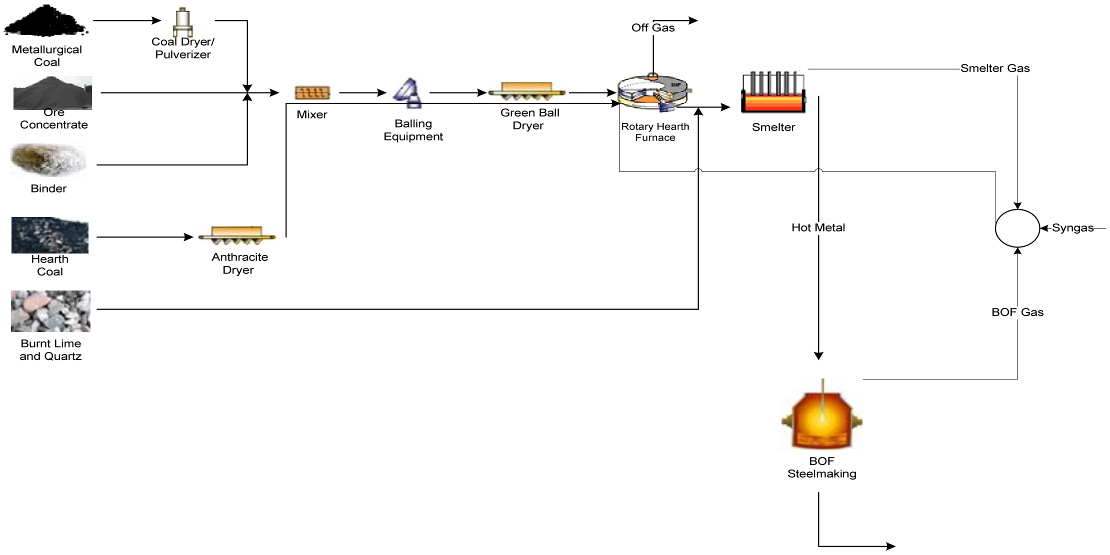

Figure 4: Block flow diagram of the Rotary Hearth and Smelter Process

Table 4 RHF/Smelter Operating Parameters

Parameter	Ore 1 Conventional	Ore 2 Conventional	Ore 3 (TiMag1)	Study (TiMag2)
Titania load, kg/thm	0	<50	50	54.5
Rotary Hearth Furnace				
Natural gas rate (GJ/t DRI)	4.8	4.5	4.4	-
Oxygen enrichment	0	0	4%	4%
Coal rate (Total kg/t DRI)	380	350	340	400
Productivity (ton/m2 hearth)	52	45	45	45
Capacity	350	450	490	490
Smelter				
Power consumption (kwhr/t)	800	640	680	810
Flux consumption (kg/t)	40	30	25	47
DRI (kg/thm)		1287		1421
Fe Yield (%)	98%	98%	98%	98%
BOS offgas recovery (MJ/thm)	0	0	0	0.88
Smelter offgas recovery (MJ/t hm)	0	0	0	0.99
RHF heat recovery (KW/tDRI)	8	8	8	8
Process units needed for 1.5 Mtpa	5	5	5	5

To reduce the fuel rate of the furnace it is important to consider oxyfuel burner technology. This can be done through conventional low enrichment (<9% O_2 enrichment), gas recirculation and synthetic air configurations and flameless burners using 100% enrichment. Although all schemes are feasible, the conventional O_2 enrichment and flameless burner technologies look most feasible.

Table 5 RHF/Smelter Hot Metal Chemistry

Parameter	Ore 1 Conventional	Ore 2 (Conventional)	Ore 3 (TiMag1)	Study (TiMag2)
Carbon	3.3	3.4	3.6	3.5
Silicon	0.3	0.07	0.3	0.20
Titanium	0.2	0.002	0.2	0.16
Vanadium	0.1	-	0.1	0.09
Manganese	0.2	-	0.2	0.05
Sulphur	0.03	0.01	0.03	0.035

Using the optimum configuration, and recovery of all BOS and Smelter off gases it is possible to reduce fuel gas consumption and power needs. This reduces purchased utility cost. The iron yield is high due to Smelter reduction and recirculation of off gas dust to the process. Provided that power is affordable and suitable coals are available the RHF + Smelter, provides a suitable alternative to the TiBF.

7 THE ITMK3 PROCESS AND ITS IMPLICATION TO TIMAG ORES

The Itmk3 process is an exciting development by Kobelco. This process builds on the concept of the RHF process, by using a high temperature final reduction-smelting zone to complete reduction, and to separate the gangue and iron by smelting. The process is in the early stages of commercialization, with the first commercial plant commissioned at Mesabi.

However, when TiMagnetite ores are used as basis of the concentrate Ulvospinels of Titanium Magnetite exist, which is difficult to reduce in the preheat section of the RHF. Under reducing conditions at temperatures < 1000^{o}C, it is estimated that only 50% of Ulvospinels will be reduced, which will increase the burden on the final reduction-smelting zone.As a result the temperature of final reduction may be increased by 50^{o}C, which may negatively impact on furnace life. This increases the gangue rate in the smelting stage, and may cause losses in iron as well as poor nugget- slag separation. To overcome this problem the process is slowed down to allow for high temperature reduction, and to ensure reduction of all magnetite not present in the ulvospinel phase. Approximately 20% of furnace capacity is lost in this way.

In regards to TiC and TiN formation, it is thermodynamically unlikely to form as the activity of carbon and titanium is never high enough to enable TiC formation and the thermodynamics is far from equilibrium.

However, in spite of these risks, ITmk3 process eliminates a Smelting stage, which allows the steelmaker to reduce cost. The process is also kinetically fast as the higher smelting temperatures allow for faster reduction than can be achieved in a conventional RHF. As a result the process productivity is high, and overall energy consumption is lower.

When the productivity of the RHF +Smelter is compared to the Itmk3 process, it is noticeable that this route requires one major processing unit less to produce 1.5 Mtpa. In addition the energy requirement is less, particularly of electrical power. However, the RHF+Smelter do produce a liquid metal that can be desulphurised and dephosphorised at low cost.

Table 6 ITMk3 Nugget Compositions**Parameter**	**Ore 1 Conventional**	**Ore 2 (TiMag2)**	**Study (TiMag3)**
Carbon	3.2	3.2	2.99
Silicon	0.1	0.2	0.07
Titanium	-	0.3	0.08
Vanadium	-	0.5	0.12
Manganese	0.08	0.4	0.16
Sulphur	0.06	0.03	0.03

8 ECONOMIC EVALUATION OF ALTERNATE IRONMAKING OPTIONS

Hatch has developed a sophisticated range of cost models, to select alternative iron and steel making technologies and to evaluate the value in use of various input materials. The proposed options for treating TiMag ores can now be evaluated using these models under the following conditions;

- Two scenarios for input cost factors have been developed to approximate site conditions favourable to integrated steelmaking and alternatively, for mini-mill steelmaking
- Battery limits are defined in flowsheet in figure 1
- The technologies have been evaluated to the liquid steel stage, to ensure that the system impacts on steelmaking is considered as well,
- Discount of 25$/tonne for TiMag ores with 4% TiO_2 is applied to account for higher processing.

Table 7 - Input Cost Assumptions

Cost factor	**Scenario A**	**Scenario B**
Coking coal ($/tonne)	200	350
PCI coal ($/tonne)	180	135
Scrap price ($/tonne)	300	300
Iron ore price ($/ton dmtu)- TiMag ores	150	150
Iron ore price ($/ton dmtu)	175	175
Power price (c/kwhr)	10	5
Natural gas prices ($/GJ)	8	5

Note: all cost on ex works basis, allowing for 20$/tonne delivery cost

Scenario A reflects conditions where a site has access to good local hard coking coal, but operates in an area where power prices and gas prices are high. As a result this fits the conditions for a TiBF best. On the other hand Scenario B works well with alternative ironmaking technologies, since it advantages Smelters which are power intensive and RHF's which need fuel gas combined with good PCI type coals. Table represents a cost driver comparison for all three technologies across the 2 scenarios.

Table 8 - Cost Driver Comparison

	Scenario 1					Scenario 2				
	Value	Classification	tiBF	RHF	ITMk3	Value	Classification	tiBF	RHF	ITMk3
Coking Coal	$200 / t	Good	✓✓✓	-	-	$350 / t	Bad	×××	-	-
PCI Coal	$180 / t	Good	✓✓	-	-	$135 / t	Bad	×××	-	-
Gas	$8 / GJ	Bad	×	××	××	$5 / GJ	Good	✓	✓✓✓	✓✓✓
Power	$10 / MWh	Bad	×	××	××	$5 / MWh	Good	✓	✓✓✓	✓✓✓

The relative advantages translate to different financial outcomes. In Scenario 1, the TiMag furnace presents the better technology than all alternatives proposed, due to the high input costs for power and natural gas. Interestingly the Scenario also shows that the TiBF has a lower operating cost and better returns than the conventional blast furnace. This is expected due to the high prices that currently hold for conventional iron ore and the good energy efficiency that TiBF has now attained, if given suitable raw materials.

However, under conditions where natural gas and power is comparatively affordable sources of energy, the alternate technologies present a better proposition. In these cases, the low OPEX costs for the Itmk3 and EAF combination wins out. However, where the TiO2 contents rise too high, or impurities contents of Sulphur and Phosphorous are too high for the EAF to refine the RHF+Smelter presents a good alternative.

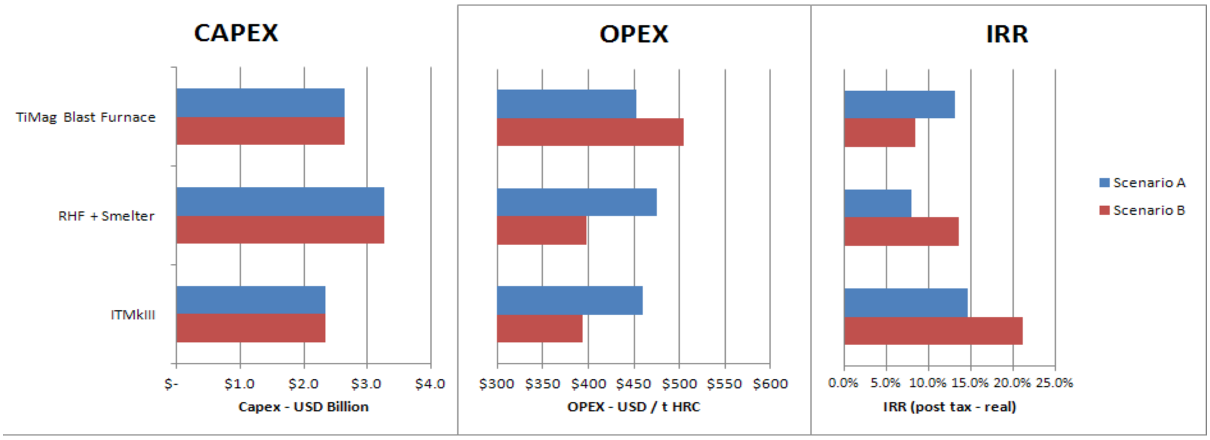

Figure 5 - Comparison of Financial Results for Scenario A and B

The TiBF has slightly higher CAPEX to the Itmk3 process, and is technologically the most mature process. However, its OPEX is higher due to coking coal requirements, and as a result, its IRR lags the Itmk3 process.

The Rotary Hearth +Smelter + BS has a higher Capex due to the Smelting step. However it is robust, and on high Ti ores (> 7% TiO2), it is the best option due to it high yield and technical feasibility.

9 CONCLUSIONS

Rotary Hearth Furnace-Smelter combination, ITmk3 process and Titania-magnetite blast furnace were compared for high Titania ore processing. The benefits of each technology were evaluated with emphasis on technology configuration, process parameters and local conditions.

The analysis shows that the selection of the appropriate technology depends on local cost factors and steel demand. For large installations able to source coking coal at reasonable cost, the Ti BF with maximum TiO2 load of about 50-60 kg/thm should be considered as the technology of choice. However, for mini-mills favored by low cost natural gas and power the RHF + Smelter process will be a suitable alternative. If the Itmk3 is successful, it will represent a breakthrough as it will allow for the wide use of Ti bearing ores in EAF steelmaking.