IRONMAKING TECHNOLOGY SELECTION FOR SITE SPECIFIC CONDITIONS[1]

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Abstract
A methodology for selection of ironmaking technology for specific site conditions has been developed and used for practical applications. The methodology is based on a two stage predetermined process of technical and economic analysis to screen and eliminate the unfavourable technologies for certain site condition. The first stage includes an evaluation of all available data applied to specific ironmaking technologies with the selection of up to three of the best technologies based on risk analysis, simple pay back period, factored capital cost analysis and operating cost estimates. The second stage includes a detailed financial analysis to select the best applicable technology. Application of this methodology has facilitated Hatch's recommendation and/or rejection of available ironmaking technologies for several global iron and steel companies to meet their specific needs.
Key words: Technology selection; Ironmaking; Site conditions; Economical analysis.

METODOLOGIA E RESULTADOS DA SELEÇÃO DE TECNOLOGIAS DE REDUÇÃO DE FABRICAÇÃO DE FERRO PARA CONDIÇÕES ESPECÍFICAS

Resumo
Este trabalho apresenta o desenvolvimento e aplicação prática de uma metodologia para seleção de tecnologia de fabricação de gusa para condições locais específicas.
A metodologia é baseada num processo conduzido em dois estágios de análise técnica e econômica com intuito de filtrar e eliminar as tecnologias desfavoráveis sob certas condições. O primeiro estágio inclui uma avaliação de todos os dados disponíveis aplicados a uma tecnologia específica com a seleção de até três das melhores tecnologias baseadas em análise de risco, período de retorno simples ("pay-back"), análise de investimento de capital e de custos de operação. O segundo estágio inclui uma avaliação econoômica-financeira mais detalhada para selecionar a melhor /mais viável tecnologia . A aplicação desta metodologia vem facilitando a recomendação e/ou rejeição, por parte da HATCH, de tecnologias de fabricação de gusa disponíveis para várias siderúrgicas com o objetivo de atendimento de necessidades específicas.
Palavras-chave: Seleção de tecnologias; Fabricação de gusa; Condições locais; Análise econômica.

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INTRODUCTION

Substantial growth in hot metal, pig iron and DRI/HBI demand is expected globally over the next 20 years. The growth of the preferred iron metallic path for expanding steelmakers depends on the steel quality requirements, environmental foot print, and lowest cost of production. Ironmaking is often a pivotal technology in the steelworks configuration. The selection methodology for the best suited ironmaking technology for a given site is presented in this paper. Specific Case Studies are provided to demonstrate the selection process.

When developing a review of applicable technologies, the first and most essential element for technology selection is to perform a market study of the steel to be produced. The goal of the market study is to predict the future steel product demand, quality and price trends applied to the future facility. Once the market opportunities and weaknesses are understood, the best site specific process technologies can be selected by applying a techno-economical evaluation to each potential technology while considering the combined impact of technology, cost of production and transportation.

Hatch has developed and applied a reliable methodology for technology selection, which is based on a two-stage approach. The first stage includes a broad evaluation of all available site specific data followed by selection of up to three candidate ironmaking technologies based on a risk analysis, simple pay back period calculation, factored capital cost analysis and operating cost estimates. The second stage consists of a detailed financial analysis of the shortlisted ironmaking technologies, resulting in a final selection of the best suited technology.

During the first stage of evaluation Hatch applies a preset process of technical and economic analyses to screen and filter all available technologies. The key evaluation metrics are as follows:

- Requirements for the final steel product
- Requirements and availability of raw materials
- Reductants and fuel requirements and their related quality
- The principles of operation
- A concept level flow sheet for each technology
- A mass and energy balance and estimation of the consumption numbers
- A review of scaling principles for each technology
- Analysis of the technical issues
- Risks assessment with respect to scaling, state of the development of the technology, and complexity of the operation
- The estimated operating cost based on the key cost drivers and best practice operating conditions;
- The complete capital cost estimate, including core process units as well as any infrastructure directly associated with the process.

The second stage of the Hatch review process involves a detailed financial analysis. This includes the analyses of local tax and depreciation implications and an analysis of sustainable maintenance. These aspects of the project are best evaluated utilizing an IRR/NPV estimate, based on discounted cash flow analyses and analysis of project financing impact. The proposed methodology is robust, based on clear and defendable principles, and is of sufficient depth to preclude a poor selection.

Case Studies

The following case studies illustrate the main features of Hatch's selection methodology:

Case Study 1

Client A engaged Hatch to conduct a market study for the sale of iron units as either iron concentrate, Direct Reduced Iron (DRI), Hot Briquetted Iron (HBI), pig iron, or nuggets. If concentrate was not the preferred route, Hatch was to recommend the most viable ironmaking technology for a plant of 2.5 million ton of iron product capacity per year. The technology was to be coal based, as natural gas was not readily available in the region.
Client A was the owner of the iron mine and bituminous coal deposits. At the time of the selection study, the mine and concentrator were still in development and the client needed to understand the project's economic viability based on the sale of concentrate or whether it would be necessary to produce a value added product, such as DRI, HBI, pig iron or nuggets
The market study results clearly demonstrated that the sale of iron ore concentrate would not be profitable. To ensure a profitable project, further processing to produce and sell a value added product in a form of pig iron, DRI or nuggets was required.
The quality of iron ore concentrate (Size -100% <0.2 mm) and coals are shown in Table 1 and Table 2.

Table 1: Iron ore concentrate quality, %

	Fe_{total}	FeO	CaO	MgO	SiO_2	Al_2O_3	MnO	TiO_2	S	P_2O_5
Concentrate	68.7	29.3	1.4	0.33	1.5	0.85	0.18	0.13	0.1	0.08

Table 2: Available coals, %

	FC_{dry}	VM_{dry}	Ash_{dry}	S
Anthracite (Coal A), normalized	77.5	12.9	9.6	0.4
Bitominous (Coal B), normalized	57.8	19.2	23	0.7

Stage 1 Review

The characterization of the evaluated ironmaking technologies during the first study stage is presented in Table 3 and Table 4.

Table 3: Major characteristics of evaluated ironmaking technologies

Technology	**Blast Furnace**	**COREX**	**Midrex & Coal**	**HYL & Coal**	**Midrex & Gas**	**HYL & Gas**
Typical capacity, tpa	3,000,000	1,500,000	1,300,000	1,100,000	1,800,000	1,600,000
Minimum size, tpa	500,000	800,000	300,000	200,000	400,000	250,000
Operating time (%)	97	92.5	91.3	91.3	91.3	91.3
Configuration (Major equipment. Material handling system required in all cases)	1*Blast furnace, 1*Coke oven, 1*Pellet plant Pig caster 1* PCI plant	1*C-3000 1*Shaft furnace 1*Pellet plant 1*Oxygen plant Pig caster	1*Shaft furnace 1*Coal gasifier 1*Gas conditioning 1*gas prehater 1*Pellet plant 1* Coal grinding 1* CO2 removal	1-Shaft furnace 1*Coal gasifier 1*Gas conditioning 1*gas prehater 1* Pellet plant 1* coal grinding 1* CO2 removal	1*Shaft furnace 1*Reformer 1*Pellet Plant	1*Shaft furnace 1*gas pre-heater 1*CO2 removal 1*Pellet plant
Ore chemistry:						
%Fe (tot)	>53	50-67	>67	>67	>67	>67
%SiO_2	<4	<4	<1.5	<1.5	<1.5	<1.5
%P (max)	<0.08	<0.08	<0.03	<0.03	<0.03	<0.03
% S (max)	<0.6	<0.6	0.01	0.02	<0.015	<0.01
Ore Size (mm)						
Pellets	6-50	6-20	8-18	6.3-16	8-18	6.3-16
Lump	8-50	5-35	10-24	10-24	10-24	10-24
Product:	Pig Iron	Pig Iron	DRI/HBI	DRI/HBI	DRI/HBI	DRI/HBI
w-t% Fe metallic	96	96	89-93	89-93	89-93	89-93
w-t% Carbon	4.5	4.5	0.8	0.4	1-3.5	1-5
Slag rate, kg/t product	260	196	NA	NA	NA	NA

Although natural gas was not available, two natural gas based technologies were presented for the purpose of comparison at the client's request.

Fluidized bed technologies are also available for DRI/HBI production. However, these technologies operate on natural gas as a reductant and a fuel. Also, fluidized bed processes have exhibited a poor performance history to date. As such, Hatch did not include them in the list of potential ironmaking technologies.

Rotary kiln, rotary hearth, and multi-hearth furnace technologies for DRI production were not considered, as they do not produce a merchant quality DRI product. Typically, these technologies are applied at facilities where the DRI produced is consumed at the steelmaking shop located at the same steel works.

To limit risk, only well proven ironmaking technologies or technologies currently at industrial or large demo plant operation were taken into consideration.

Blast furnace technology needs high quality metallurgical coal to produce the coke required for blast furnace operation. Other technologies can operate with cheaper bituminous type of coals. Some technologies, such as rotary hearth furnaces and ITmk3® currently require natural gas or oil as a source of heat. Hatch strongly believes that pulverized coal combustion could become a good substitute for oil or natural gas.

The current status of the evaluated technologies is as follows:

Table 4: Major characteristics of evaluated ironmaking technologies

Technology	Tecnored	RH & Smelter	ITmk3	RK & Smelter	FINEX	HIsmelt	Romelt
Typical unit capacity, tpa	700,000	1,000,000	550,000	750,000	1,500,000	830,000	300,000
Minimum capacity, tpa	150,000	500,000	550,000	500,000	1,500,000	830,000	150,000
Actual operating time (%)	92	80	>92	85	92.5	92	92.3
Configuration (major equipment. Material handling system required in all cases)	1*Reactor 1*green balling and agglomeration Pig caster	2*rotary Hearths 1*Smelter 1*green balling Pig caster	1* rotary Hearth 1* rotary cooler 1*green balling 1*dryer Magnetic separator	4*Kilns 1*Smelter Pig caster	1*C-3000 1*Megat-rain fluidized bed 1*coal briquette-ting Pig caster	1*SRV 1* Ore pre-heater Coal and flux injection Pig caster	1*Furnace 1*Oxygen plant Pig caster
Ore chemistry: **% Fe(tot)** **% SiO2** **%P (max)** **%S (Max)**	 65 4-5 <0.08 N/A	 64 4-5 <0.08 <0.12	 58-70 4-6 <0.05 <0.1	 64 4-5 <0.08 <0.12	 50-67 4-6 <0.08 <0.6	 53-67 4-6 <0.12 N/A	 28-67 4-10 <0.1 N/A
Ore size (μk) **Pellets** **Lump unit)** **Concentrate/Fines**	 0-100	 0-100	 0-100	mm 6-22 5-25 0-12	 75–500	mm 0-20 0-6	mm 0-20 0-20
Product:	Pig iron	Pig iron	Nuggets	Pig iron	Pig iron	Pig iron	Pig iron
w-t% Fe metallic	>94.2	96.5-97	95.7-97.5	96.4	96	95.2-96.3	95.3-95.5
w-t% Carbon	3.8-4.3	3.4	2.5-3.5	3.4	4.5	3.8-5	4.4-4.6
Slag rate, kg/t product	200	170	200-350	320	200	350	320

- **Blast Furnace:** Most proven ironmaking technology with more than 1,000 installations in the world. Capacity of the blast furnace ranges from 300,000 to 4,400,000 tpy of hot metal/pig iron.
- **COREX® Process**:Capacity range from 800,000 to 1,500,000 tpy. 5 installations in the world.
- **Finex® Technology:** One plant is in operation at Posco, South Korea with 1.5 million ton annual capacity.
- **Midrex® and HYL® Gas Based Technologies:** Numerous installations exist in the world.
- **Midrex® and HYL® Coal Based Technologies:** Only one plant operates utilizing a reducing gas with similar composition to proposed coal gasification synthetic gas – Saldana Steel (ArcelorMittal), South Africa, Midrex® Megamodule. This plant operates using reducing gas produced in a Corex® melter-gasifier.
- **Rotary Kiln/ Smelter Combination:** There are several industrial installations in the world. Examples include New Zealand Steel and Highveld (South Africa).
- **Rotary Hearth/Smelter Combination:** There are several installations in the world. Examples include Iron Dynamics (Indiana, USA) and Inmetco (USA). Three rotary hearth furnaces are in use in Japan for waste materials treatment.

- **ITmk3® Process:** The first industrial ITmk3® process plant is in the commissioning stage and is expected to start routine operation in September 2009. Two other plants are in the engineering and construction stage in USA and Kazakhstan.
- **Tecnored® Process:** The Tecnored® Process is currently at the industrial demonstration plant stage, not yet tested, in Pindamonhangaba (São Paulo, Brazil) and has an annual design capacity of 75,000 tons.
- **HIsmelt® Process:** First and only HIsmelt® process industrial plant (Kwinana, Western Australia) has been in the ramp-up stage over the past three years
- **Romelt® Process:** First industrial Romelt® plant (Burma) is currently being constructed. It will have a design annual capacity of 200,000.

The consumption numbers, capital and operating cost rating. and pay back period for the evaluated technologies are presented in Table 5 and Table 6.

Table 5: Major consumption numbers, capital and operating costs and pay-back period

Technology	**BF**	**COREX**	**Midrex & Coal**	**HYL & Coal**	**HYL & Gas**	**Midrex & Gas**
Capacity (tph per unit)	353	217	162.5	137.5	137.5	225
Smelting capacity (tph/unit)	353	185	N/A	N/A	N/A	N/A
Labour (mnhrs/t prd)	0.1	0.3	0.25	0.2	0.12	0.11
Concentrate/pellets (t/t product)	1.5	1.5	1.45	1.45	1.45	1.45
Limestone+dolomite, (kg/tprd)	90	148	8	9		
Lime/cement (kg/t prd)					5	1.5
Coal dry (kg/t prd)	734	650	500	447		
Oxygen (Nm^3/t prd)	30	400	245	280	60	20
Natural Gas (GJ/t prd)	0.2	0.1	0.1	0.1	10.2	9.9
Electricity (kWh/product)	125	601	284	249	60	115
Capital cost (rank)	5	12	6	7	2	1
Operating Cost (rank)	13	12	2	3	6	5
Pay back period. (years/rank)	2.8/8	4/12	2.5/5	2.8/9	1.6/3	1.3/1

The Stage 1 selection process yielded the following conclusions:

- The high levels of phosphorus and sulphur placed restrictions on selection process. The processes that produced hot metal had the advantage of additional hot metal treatment opportunities; de-phosphorization to reduce phosphorous to commercial grade pig iron; de-sulphurization to reduce sulphur to commercial grade. This advantage applies to Blast Furnace, Finex®, Corex®, Rotary Hearth/Smelter and Rotary Kiln/Smelter combinations, Tecnored and Romelt.
- Romelt®, HIsmelt® and Tecnored® were not recommended due to the technical risk, as the technologies were not yet proven at an industrial scale.

Table 6: Major consumption numbers, capital and operating costs and pay-back period

Technology	Tecnored	2RH & Smelter	ITmk3	4RK & Smelter	FINEX	HIsmelt	Romelt
Capacity (tph per unit)	86.9	188.4	68.75	120	185.1	103.0	37.1
Smelting capacity (tph/unit)	86.9	142.7	68.75	100.7	185.1	103.0	37.1
Labour (mnhrs/t prd)	0.64	0.5	0.25	0.55	0.4	0.28	0.6
Concentrate/pellets (t/t product)	1.5	1.5	1.45	1.5	1.5	1.66	1.49
Limestone+dolomite, (kg/tprd)			170	154			
Lime/cement (kg/t prd)	150	80			80	120	307
Coal dry (kg/t prd)	850	470	410	815	546	900	956
Oxygen (Nm^3/t prd)	0	10	0	10	370	268	964
Natural Gas (GJ/t prd)	0.1	3.2	5.6	0.1	0.1	0.1	0.1
Electricity (kWh/product)	140	500	200	910	568	333	622
Capital cost (rank)	4	9	3	10	11	8	13
Operating Cost (rank)	1	4	7	11	10	9	8
Pay back period. (years/rank)	1.5/2	2.7/6	1.7/4	3/10	3.4/11	2.7/7	6.2/13

- HYL® and Midrex® coal based processes: Client A's iron ore concentrate chemistry (specifically high sulphur and phosphorus) limited the use of direct reduction ironmaking processes that produce a DRI product. The product quality was expected to be unsuitable for the merchant HBI market. Even if a market was found, the expected penalty on product price would be severe. As such, coal based Midrex® and HYL® were disqualified.
- ITmk3®: The nuggets produced by the ITmk3® process are preferred by most steel producers. The nuggets carry high value in EAF and BOF operations due to their low gangue and sulphur content while providing good melting characteristics. Therefore, nuggets were expected to carry a premium as compared to DRI/HBI. The expected high phosphorus level in the product would likely reduce the premium and may limit the nugget composition in an (EAF) charge. The ITmk3® process is most suitably located at the iron ore mines due to its modular design, use of conventional equipment and commonalities with pelletizing plants. I ITmk3® currently requires natural gas or oil as a source of heat; however, pulverized coal combustion could be applied. Absence of commercial ITmk3 plant represents a higher risk than mature processes..
- Direct reduction and smelting: For capacities above 1 Mtpa, the Rotary Kiln/Smelter and the Rotary Hearth/Smelter were also considered in addition to the ITmk3® technology. The rotary hearth furnace is typically more attractive, as it has a significantly shorter pay back period.
- COREX® was not suggested due to high capital cost and a relatively poor return period. The process did not display an advantage over the smelter based processes or the Finex® technology.
- Finex® could only be considered for capacities above 2 Mtpa. Although Finex® performs better than the Corex® process based on operational cost, it still required significant scale and investment (>2 Mtpa) to become viable. The fluidized bed

added complexity to the process flow and could limit the types of iron ores that can be used.

- The Blast furnace route should be only be considered at production levels above 3Mtpa, as this route is capital intensive and only becomes economically profitable at a large scale of operation. It is best suited for an integrated steel works and requires pellets/sinter and coke production, and their related/significant capital investment.

Based on Stage 1 results the Rotary Hearth Furnace/Smelter combination and ITmk3® process were selected as most viable technologies for Client A.

Stage 2 Review

The final technology selection is determined by the results of the financial modelling – Stage 2 of the developed methodology. Results of financial modeling of the two competing processes selected during the Stage 1 review process are presented in Table 7.

Table 7: Financial modeling results

Technology	Rotary Hearth and Smelter	Rotary Hearth and Smelter	ITmk3®	ITmk3®
Coal Type	A	B	A	B
# Rotary Hearths	5	5	5	5
# Smelters	3	3	0	0
Capacity (*1000) tpa	2500	2500	2500	2500
Operating factor for RHF, (%)	92.3	92.3	91.3	91.3
Operating factor for smelter, %	85	85	N/A	N/A
IRR (%)	9.6	10.5	14.2	15.2
NPV (USD Million)	-236	-161	167	325

Based on the results presented in Table 7, the ITmk3® (Figure) process was recommended to Client A as the most viable process meeting its requirements for acceptable IRR and NPV values.

Case Study 2

Client B engaged Hatch to conduct a high level conceptual study for a 5.7 million ton per annum slab plant. The project was to take advantage of local circumstances, such as availability of iron ore, inexpensive green electrical power, and the opportunity to export process generated fuel gases to an adjacent industrial establishment. Natural gas was not available in the region.

The following design principles were proposed and agreed upon with the Client B.

- Prioritize maximum use of internally generated gases for chemical reduction, followed by fuel gas use as a secondary priority
- Flexibility to use lower quality iron ores and coals
- Apply only industrially proven technologies
- Selection of the most suitable capacity of the plant would be dependant on each selected production route but be in the range of 5-5.7 million ton of slabs per annum
- No other purchase of any iron bearing raw materials except iron ore concentrate.

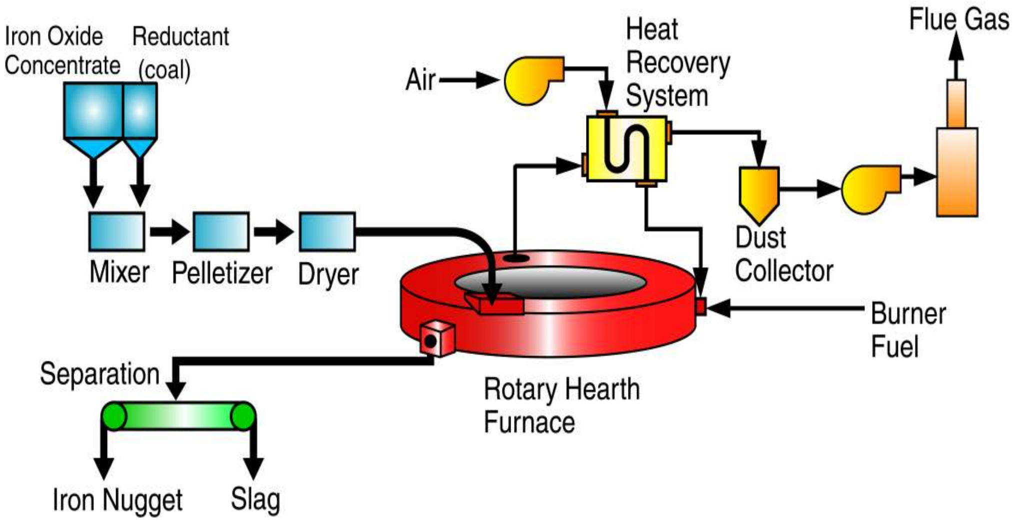

Figure 1: ITmk3® process flowsheet.

Based on the above design principles, the number of available technology options was quickly reduced, Hatch subsequently selected the following two major technological routes for further evaluation:

- Two COREX® C-3000 units (Largest industrial design capacity) combined with DRI furnaces (Saldanha Steel, ArcelorMittal configuration)
- A Blast Furnace based plant

Unlike in Case Study 1 an ITmk3® process was not considered in this case mainly because it was not industrially proven. Also 11 units would be necessary to meet the production requirements. Such a large quantity of operating units would require significant space, complex utility requirements, higher manpower needs, and complex operational logistics.

Based upon the two primary process routes, Hatch studied three process options:

- Coke Plant/Pellet Plant/Blast Furnace/BOF Steelmaking/Slab Casting
- Coke Plant/ (1/3) Pellet Plant/Sinter Plant/Blast Furnace/BOF Steelmaking/Slab Casting
- Pellet Plant/COREX® Plant/Midrex/Conarc® Steelmaking/Slab Casting

Option 1

Process Route: Pellet Plant/Coke Plant/Blast Furnace/BOF Steel Making/ Slab Casting

Plant units:

Coke plant:	By-product type coke plant
Blast Furnace:	Two blast furnaces;
Steel Making Shop:	Two BOFs
Casting Shop:	Two 2 strand slab casting machines
Ancillary Systems:	All plant operation supporting systems

Option 2

Process Route: Sinter Plant/Coke Plant/Blast Furnace/BOF Steel Making/ Slab Casting

Plant units:

- Sinter Plant: 2 strand sinter plant
- Coke plant: By-product type coke plant
- Blast Furnace: Two blast furnaces; Sinter:Pellet rate: 70:30
- Steel Making Shop: Two BOFs converters
- Casting Shop: Two 2 strand slab casting machines
- Ancillary Systems: All plant operation supporting systems

Option 3

Process Route: COREX® + DR/ EAF Steel Making/ Slab Casting;

Plant units:

- COREX® plant: Two - C3000 units;
- DR plant: Two 7.2 m diameter Midrex® DR furnaces;
- Steel Making Shop: Three CONARC® electric arc furnaces;
- Casting Shop: Two 2 strand slab casting machines;
- Ancillary Systems: All plant operation supporting systems.

As Client B did not require financial evaluation of ironmaking technologies for its specific site conditions, the procedure of analysis was simplified, skipping Stage 2 of the developed methodology. Selection of the best technological route was based on a simplified analysis of the capital and operating costs and pay back period. The results of the financial modeling for each key parameter are presented in Tabel 8.

Table 8: Simple pay back period estimate

	Option 1 BF Route with pellet plant	**Option 2 BF route with sinter plant**	**Option 3 COREX + Midrex**
Annual production, million ton of slabs	5.7	5.7	5.7
Relative to option 3 capital cost	1.1	1.072	1
Relative to option 3 operating cost	0.953	0.975	1
Relative to Option 3 pay back period	0.843	0.925	1

Based on Table 8 results the Pellet Plant/Blast furnace (Option 1) route was recommended to the Client B as the most preferred option for a 5.7 million ton per annum slab plant for specific site requirements. The plant flowsheet is presented in Figure 2.

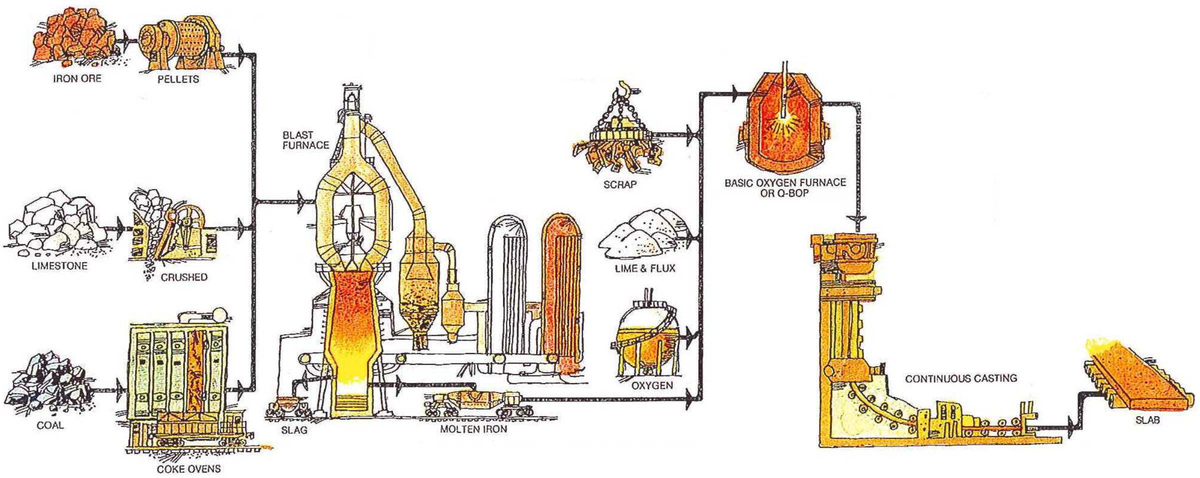

Figure I: Blast furnace based slab plant.

Case Study 3

Client C requested Hatch to evaluate applicability of rotary kiln (RK) technology to process their fine ore to produce solid pig iron. The capacity of the proposed plant was 700,000 tonne of pig iron per annum. Client C specifically asked Hatch to evaluate New Zealand Steel flowsheet for hot metal production as one of the option. In this case study hatch evaluated two major technological options: NZS flowsheet with respect to processing Client' C ore (Figure) and long rotary kiln without MHF.

The chemical composition of iron ore and coals is presented in Table 9 and Table 10. 83 % of ore fines are in the range of 44 to 650 µk, 7% in the range of 1-0.65 mm and 10% below 44 µk.

Table 9: Ore chemical composition, %

Fe_{total}	SiO2	Al2O3	CaO	MgO	S	P	LOI	Moisture
67-68	0.95-1.3	0.5-0.56	0.59-0.63	0.19	0.1	0.036	1.87	3

Table 10: Coals chemical composition, %

	C_{daf}^{fixed}	VM_{daf}	Ash	Moisture	S_{total}	P_{total}	LHV, kkal/kg
Coal A (basic coal)	80-83	17	18	10	0.55	0.66	8,000
Coal B (high VM)	55.5	44.5	5	8	0.42		7,750

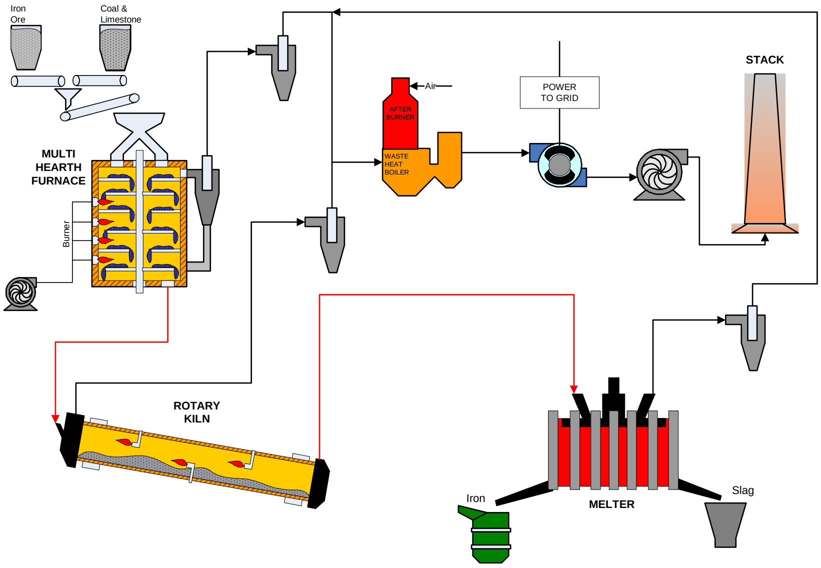

Figure 3. Requested by Client C process flowsheet.

Combined results of Stage 1 (simple pay back period) and Stage 2 (financial modeling) evaluation are presented in Table 11.

Table 11: Simple Pay back period, IRR and NPV for various scenarios

	Scenarios						
Parameter	**1 Base Case**	**2**	**3**	**4**	**5**	**6**	**7**
Process Configuration	4 x Multi Hearth furnaces					None	1 x Pellet Plant
	4 x Rotary Kilns					4 x Long RK	
	1 x Smelter						
DRI Metallization, %	80	86	92	92	92	92	92
Type of coal	A	A	A	B	C	A	A
Payback, years	24	24	24	23	24	24	24
NPV, USD millions	(309)	($317)	($329)	($281)	($330)	($343)	($315)
IRR, %	-4.3	-5.5	-8.2	-1.5	-8.5	-2.7	-4.2

Based on specific site conditions and Table 11 results Hatch did not recommended to the Client C to proceed with ironmaking project based on rotary kiln technology.

Conclusions

- A Fixed methodology for selection of the most suitable ironmaking technology for specific site conditions has been developed and utilized by Hatch;
- This methodology has been successfully applied to various global regions, considering the client specific limitations and demands;
- The risk of implementation for new ironmaking technologies plays a significant role in the technology selection process;
- Selection of the most suitable ironmaking technology is significantly dependant on plant location, raw material availability, fuel/reductant availability, quality and pricing of raw materials, market conditions and other site-specific limitations.