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BLAST FURNACE VALUE IN USE MODEL AND ITS APPLICATION FOR IRON ORE PROCESSING[1]

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Abstract

The selection of iron ore for a blast furnace is traditionally influenced by a number of factors that determine the economics and practicalities of a successful operation. Such factors include ore grade, location of the plant relative to the ore body, availability, contaminants and process suitability. Additionally, Green House Gas emissions and energy efficiency are becoming more prevalent topics and will become a factor in the selection and beneficiation of raw materials in general and iron ore in particular. Hatch has developed a sophisticated VIU (Value - In- Use) Model enabling iron ore producers to investigate the impact of replacing existing burden with a new ore on blast furnace operation and the corresponding cost implications to steel product. This knowledge allows efficient negotiations of ore prices between suppliers and steelmakers. Modelling is achieved through a mass and energy balance combined with modules to describe the effect the ores physical properties have on blast furnace productivity. The model uses standard ISO properties to calculate the impacts which are translated to the benefit (or loss) to the steelmaker in terms of cost. The paper presents a case study, showing the impacts of various ore grades for a typical integrated steel works and analyses the impact on production cost if a price on carbon is introduced. Estimated results show that if a carbon price is introduced it will make a significant difference to the Value-in-Use of various ore types.

Key words: Blast furnace; Value in use; Model; Greenhouse gas emissions.

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1 INTRODUCTION

The selection of iron ore for a blast furnace is traditionally influenced by a number of factors that determine the economics and practicalities of a successful operation. Such factors include ore grade, location of the plant relative to the ore body, availability, contaminants and process suitability.

One of the techniques utilized by Iron Ore Producers and Iron makers alike to engage in informed price negotiations is Value In Use (VIU) Modelling, whereby process simulations of the impact of the replacement Ore are modelled in order to quantify the production cost impact.

- Value in Use is typically measured using a total cost of ownership basis in the following ways
- Value in Use accruing to a steelmaker if the replacement ore is used as replacement instead of existing ore at the same ore price
- Impact in $/tonne hot metal cost, of using a replacement ore at an assumed market price
- Adjustment in replacement ore price, needed by steelmaker to compensate for the benefits and penalties in using the replacement ore

Hatch has developed a sophisticated VIU (Value - In- Use) Model utilizing these methods enabling iron ore producers to investigate the impact of replacing existing burden with a new ore on blast furnace operation and the corresponding cost implications to steel product. This knowledge allows efficient negotiations of ore prices between suppliers and steelmakers.

The regulatory risk of Green House Gas (GHG) Emissions and Energy Efficiency still pose a significant threat to the Iron and Steel industry, and complicates sourcing strategies for iron ores. For Blast Furnace Iron making typical Energy Efficiency and GHG reduction opportunities may include;

- Pulverized Coal Injection
- Top gas recovery turbines
- Hot Stoves Waste Heat recovery
- Biomass Carbon replacement

In addition the properties of the Iron Ore also have an impact and can be added to the opportunities above. This has obvious implication for the value in use of an Iron Ore, particularly where energy efficiency regulation or carbon pricing mechanisms are or will be in place.

2 HATCH VIU MODEL

The Hatch Value in Use model has been built to describe the effects of ore grade, using the standard ISO properties, on an Integrated Steel Plants operation in terms of total cost (OPEX) of production, including of all fixed costs such as depreciation, interest, labour and overheads as well as all variable costs such as raw materials, utilities, energy and consumables. The model has been developed as a series of interlinked modules and considers the replacement ore's impacts on;

- Consumption rates
- Blast furnace productivity implications
- and sustaining capital and depreciation impacts

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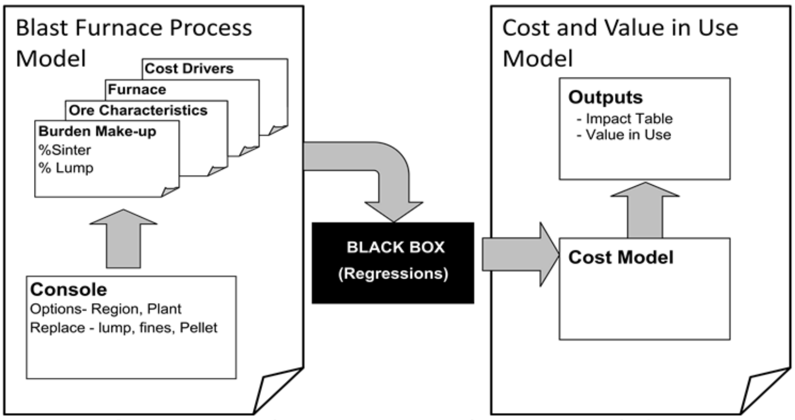

Figure 1: Model structure used for VIU modeling.

The model consist of two parts, a Production Model that calculates the impact of the iron ore on the blast furnace, using a 5 stage mass and energy balance, combined with simulations of the impact on furnace productivity impacts on furnace flooding, pressure drop and wind rate. Each simulation impact is modelled in a separate module, which is interlinked and solved iteratively for a specific scenario. By substituting progressively more of the replacement ore into the reference plant's burden, the model can calculate regressions which are used by a separate VIU cost model to calculate the impact on plant OPEX cost.

The Cost Model encompasses Coke Making, Ironmaking through to the Crude Steel stage, and models the impacts of replacing a reference case ore with another ore at varying replacement ratios on the total OPEX cost. This is used to evaluate the Value in Use of the replacement ore and thus enables efficient negotiations between Iron ore producers and steel makers.

3 MODEL FRAMEWORK

The Hatch VIU Model for the Blast Furnace is built upon a detailed process simulation of the blast furnace. This simulation considers the impact of the replacement ore's physical and chemical properties on the blast furnace productivity and cost drivers as depicted in Figure 2.

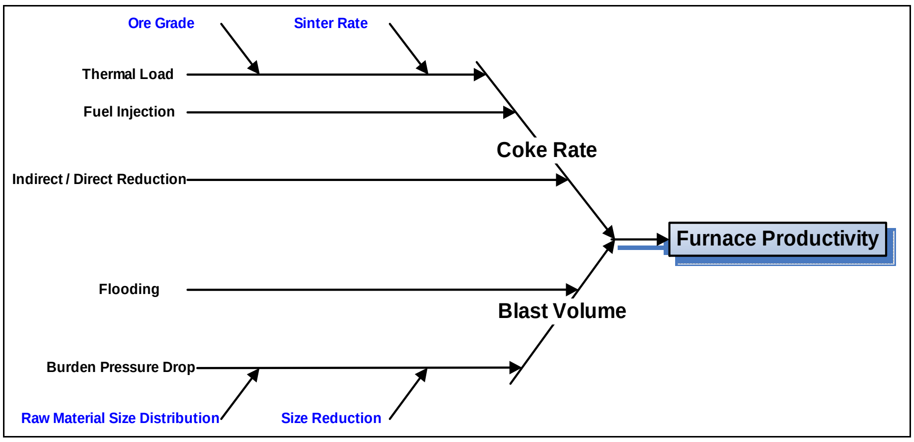

Figure 2: Impact of furnace properties on blast furnace cost drivers

The impacts of each parameter on the Blast Furnace are modelled individually using a series of calculation modules. The outputs of the blast furnace modules are

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then combined with cost modules for the steel plant to calculate the impact on overall plant OPEX cost.

4 BLAST FURNACE PROCESS MODEL

The blast furnace process model is an integrated MS Excel based blast furnace simulation, using an HSC thermodynamic platform and comprising a number of standalone modules which are solved in iterative fashion.

Using documented relationships between Key Iron ore parameters and Blast furnace operation, the process model can calculate the consumption numbers and productivity impact, given a predefined set of constraints..

The relationships defined are solved in each module according to the direction of gas flow. The model iterates to a solution using the gas flow direction, and calculates the modules of each step in consecutive fashion. Inputs to the model are defined through the following modules

- **User Console -** Allows the user to select the geographic region where the blast furnace plant is situated. Having selected this, a list of plant capacities appropriate to that region can be selected. A replacement ore is then selected from the raw materials database. The user can choose model run options from a list which can turn off certain calculation modules and affect the way the integrated model behaves. The user may specify the amounts of lump ore, sinter and pellets that make up the Fe burden.
- **Raw Materials database -** Contains chemical analyses for raw materials currently being used by blast furnace operators in the different geographical regions. The types of raw materials and prepared burden materials are lump ores, pellets, sinter, coke, injectant coal and fluxes. The console panel allows the user to specify a blend for each of the iron bearing materials and the weighted average analysis of the specified blend is transferred for calculation purposes
- **Furnace Operating Parameters and Materials Properties database -** The blend chemical analyses for all material inputs calculated in the raw materials database are transferred to this module and stored per geographical region and plant capacity. The physical properties of the blended materials such as cold and hot strengths (tumbler indexes), reducibility indexes, size distributions and CSR and CRI characteristics for coke are maintained in this database. Furthermore furnace dimensions and operating parameters, fuel rates, blast rates and product chemistries are also stored here

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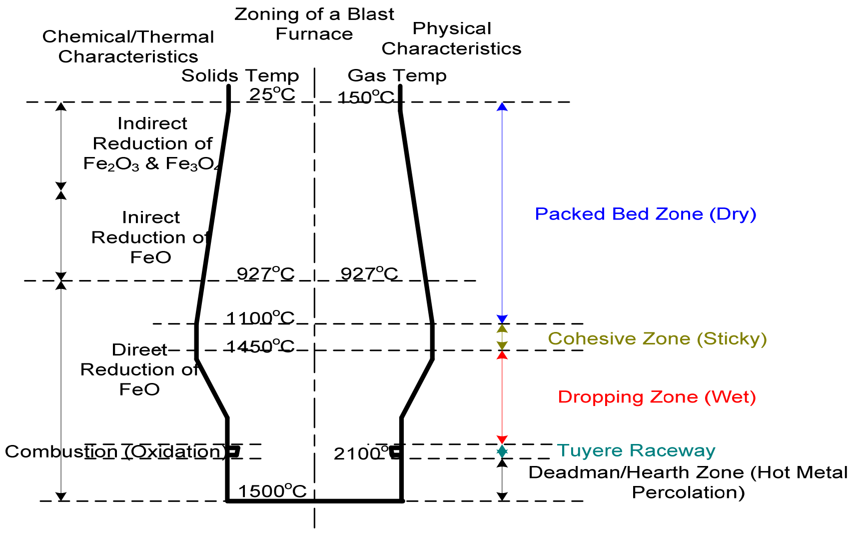

Figure 3: Five (5) zone model for the Blast Furnace

5 INTEGRATED STEEL WORKS COST MODEL

The integrated steelworks Cost model comprises of a full total cost of ownership (TCO) calculation for each of the following operating units;

- Coke Ovens
- Sinter Plant
- Pellet Plant
- Blast Furnace
- Hot Metal Treatment
- Steelmaking (BOF to LMF and/or IRUT)
- Casting (Slab, Billet, Bloom)
- Long and Flat product

The cost model combines a plant wide production and energy balance calculation, with process unit consumption rates and fixed cost assumptions. It is linked to the Blast Furnace Model by series of regression formulae which describe the effect on Blast furnace production and consumption rates for a given ore replacement from 0% (no replacement) to 100%.

The production cost calculation is performed in real terms utilizing either a Current or Long Term pricing basis and Includes depreciation and sustaining capital but excludes interest and taxes (EBIT)

Value in Use modelling is achieved by comparing production costs of the reference case against production cost with a user selectable replacement percentage and ore. The cost penalties and benefits are then summarized fore results analysis. The Value in Use can be measured as;

- The cost impact to the steel maker in terms of production cost assuming the replacement ore is the same price and the reference ore
- The Cost Impact to the steel maker at an assumed replacement ore price
- The ore price adjustment necessary to equalize the cost impacts of the replacement ore.

6 CASE STUDY

As a case study of how VIU Modelling can be used for quantifying the cost and GHG implications of a change in iron ore quality, we model the impact of

ISSN 2176-3135

2 replacement ores as sinter feed material on a typical 2MTPA Integrated steel works to the Hot Metal Stage.

6.1 Reference Plant Configuration

The reference plant is configured as per a typical integrated Steel works utilizing a 2Mtpa capacity blast furnace with 2100m3 working volume, a 10.3m hearth diameter and a 65% sinter, 17% Pellet , 18% Lump ore burden. The process uses pulverized coal injection to replace coke and the total fuel rate is 508kg/thm.

Table 1: Plant Configuration

Production Unit	Technology / Description	Product Unit	Product Mtpa
Sinter Plant	Fine ore agglomeration/fusion process – Some reductionof iron oxides	Sinter	2.13
Coke Ovens	Non - Stamp Charging By-pro duct oven batteries	Coke	0.77
Blast Furnace	Modern free-standing furnace with PW (bell less) top	Hot Metal	1.98

Table 2: Raw Material Properties

	Fe Burden			Coke		PCI Coal	
	Lump Ore	Pellet	Sinter		%		%
Fe Burden %	18%	17%	65%	C	83.5	C	50
FeTot	62.05	64.2	54.78	S	0.68	S	0.8
Basicity – B2	0.02	1.03	1.85	Volatiles	1.3	Volatiles	36
Basicity – B4	0.04	0.93	1.62	Ash	12.99	Ash	9.9
Size distribution				H2O	1.54	H2O	3
5	96	0.8	0.3	Coke Strength after Reaction (CSR)	55.4		
-5mm	4	1	0.2	Coke Reactivity Index (CRI)	27.81		
Pyrometallurgical Data				M+40	59.54		
Reducibility Index_40 (RI)	0.58	1	1.2	M+30	76.89		
Reduction Disintegration Index (RDI)+6.3	60	90	71.7	M+10	7.27		

The blast furnace KPIs are generated for the reference case utilizing the Hatch Blast Furnace Model which is calibrated against the Furnace in question. The main blast furnace operating parameters and the KPIs for the reference case are shown below.

ISSN 2176-3135

Table 3: Reference Case Blast Furnace KPI's

Parameter	Unit	Value	Parameter	Unit	Value
Daily production	t HM / day	5500	Sinter	t/t HM	1.02
Blast rate	Nm3/min	3800	BF Pellets	t/t HM (dry)	0.26
Blast temperature	°C	1124	BF Lump Ore	t/t HM (dry)	0.3
Specific Blast rate	Nm3/thm	995	Total Iron Feed	t/t HM (dry)	1.57
O2 enrichment	%	5	PCI Coal Blend	kg/ t HM	140
Productivity	t/m^3/day	2.6	Coke	kg/ t HM	359.97
Slag rate	Kg/thm	268	Limestone	kg/ t HM	1.2
Slag tap temp	°C	1500	Dolomite	kg/ t HM	0.32
Sinter Basicity		1.85	Oxygen	Nm3 / t HM	49.75
Slag Basicity - B2		1.17	Blower Air (dry, ex O_2 enrichment)	Nm3 / t HM	993.54
Slag Basicity - B4		0.95	Natural Gas	kg/ t HM	-
RAFT	oC	2100	Process Gas - Consumed	GJ /t HM	1.49
Top gas Pressure	kPa	170	Process Gas - Generated	GJ / t HM	3.95
Top gas temperature	°C	147			
Top Gas Volume	Nm^3/thm	1542			
Eta CO = CO2/(CO+CO2)	%	50.3			

Table 4: Coke Ovens and Sinter Plant Operating Assumptions

Coke Ovens			Sinter Plant		
Item	Unit	Value	Item	Unit	Value
Coal Blend	t/ t coke	1.316	Concentrate	kg/ t sinter	768.5
BFG	GJ/t coke	2.893	Limestone	kg/t sinter	30
COG	GJ/t coke	1.05	Dolomite	kg/t sinter	40
H2SO4	kg/t coke	6.43	Lime	kg/t sinter	24
By products			Coke Breeze	kg/t sinter	50
COG Generation	GJ/t coke	11.753	Fuel Gas	GJ/t sinter	0.05
Tar	kg/t coke	49.3			
Ammonium Sulphate	kg/t coke	15.3			
BTX Oil	kg/t coke	22.2			


ISSN 2176-3135

6.2 Key Cost Assumptions

In typical applications of the modelling a combination of Hatch Steel Cost Curve data, client and analyst cost data are used specific to the plant and region. For the purposes of this case study the following input cost assumptions have been used.

Table 5: Key Cost Assumptions

Item	USD	Item	USD
Sinter Fines	$170 / dmt	Coking Coal Blend	$215 / dmt
Blast Furnace Pellet	$201/ dmt	Limestone	$10 / dmt
Iron Ore - Lump	$190/ dmt	Dolomite	$6 / dmt
Scrap	$370/ t	Depreciation Cost	$40 / annual t HRC

6.3 Replacement Ore Properties

The table below shows the reference case Sinter properties against the Sinter properties when using replacement Ores A and B.

Table 6: Sinter Properties Comparison

Sinter Properties		Reference Case	Ore A	Ore B
FeTot	%	54.78	59.24	50.50
Basicity – B2		1.85	2.17	1.00
K2O	%	0.02	0.06	0.15
Size distribution				
+25mm	%	20.00	18.36	18.36
+5	%	0.30	2.24	2.24
-5mm	%	0.20	0.80	0.80
Pyrometallurgical Data				
Reducibility Index_40 (RI)		1.20	1.24	1.24
Reduction Disintegration Index (RDI)+6.3		71.70	72.36	72.36

6.4 Impact of Replacement ores on the Blast Furnace

In terms of productivity of the blast furnace we can see from

Table 7 that as expected Ore A increases the production rate slightly whilst Ore B decreases production significantly. The reason for the slowed production rate in the case of ore B can be attributed mainly to the higher coke rate and lower ore grade. The higher coke rate is due mainly to higher slag rate caused by lower ore grade. Coke degradation caused by alkali attack and a higher degree of direct reduction (Boudouard reaction) also contributed to a higher coke rate. The Increase in Production rate for Ore can be attributed to the Higher Ore grade, causing a lower slag rate and lower Coke rate.

ISSN 2176-3135

Table 7: Impact on Blast Furnace Operating Parameters and Consumption Ratios

Parameter	Unit	Base Case Value	Ore A	Ore B	Parameter	Unit	Base Case Value	Ore A	Ore B
Daily production	Tonne per day	5,533	5,544	4,812	Sinter	t/t - HM	1.02	0.97	1.08
Blast rate	Nm3/min	3,817	3,773	3,623	BF Pellets	t/t - HM (dry)	0.26	0.25	0.28
Blast temperature	oC	1124	1124	1124	BF Lump Ore	t/ t - HM (dry)	0.3	0.28	0.31
Specific Blast rate	Nm3/thm	993	979	1,084	Total Iron Feed	t/ t - HM (dry)	1.57	1.5	1.67
O2 enrichment	%	5	5	5	Coke	kg/ t - HM	359.97	357.1	385.58
Productivity	t/m3/day	2.63	2.64	2.29	PCI	kg/ t - HM	140	140	140
Slag rate	Kg/thm	274	206	428	Limestone	kg/ t - HM	1.2	1.2	69.39
Slag tap temp	oC	1500	1500	1500	Dolomite	kg/ t - HM	0.32	0.32	18.44
Sinter Basicity - B2		1.85	2.17	1	Oxygen	Nm3 / t - HM	49.75	49.75	49.75
Slag Basicity - B2		1.15	0.99	1.05	Blower Air (dry, no O2 enrichment)	Nm3 / t - HM	993.54	980	1,084.21
Slag Basicity - B4		0.95	1.03	0.95	Natural Gas	kg/ t - HM	-	-	-
RAFT	oC	2,109	2,107	2,123	Process Gas - Consumed	GJ /t - HM	1.49	1.49	1.49
Top gas Pressure	kPa	170	170	170	Process Gas - Generated	GJ / t - HM	3.95	3.91	4.26
Top gas temperature	oC	147.26	167.1	97.3					

The Hot metal composition is shown below for the replacement ores.

Table 8: Hot Metal Composition

Hot metal composition	Reference Case	Ore A	Ore B	Hot metal composition	Reference Case	Ore A	Ore B
Fe	94.1%	94.2%	93.9%	S	0.2%	0.2%	0.2%
C	4.8%	4.8%	4.8%	Ti	0.1%	0.1%	0.1%
Si	0.5%	0.4%	0.5%	Zn	0.0%	0.0%	0.0%
P	0.1%	0.1%	0.1%	V	0.0%	0.0%	0.0%
Mn	0.3%	0.2%	0.4%				

ISSN 2176-3135

6.5 Cost Impacts

The cost impacts of the replacement ores are shown below in Table X without consideration of a carbon emissions price.

Table 9: Replacement Ore Cost Impacts

		Reference Case	Ore A	Ore B
Hot Metal Cash Cost	$ / t HM	457.94	448.38	483.2
Depreciation	$ / t HM	40	39.92	46
Total	$ / t HM	497.94	488.3	529.2
Changefrom reference			-9.64	40.9

As expected by the technical results Ore A lowers production cost $9 from the reference case whilst Ore B increase production costs by $40.

6.6 Hot Metal Cost Impacts

Figure 5Figure 4 shows a Cost impact analysis of the hot metal cash cost for the two replacement ores.

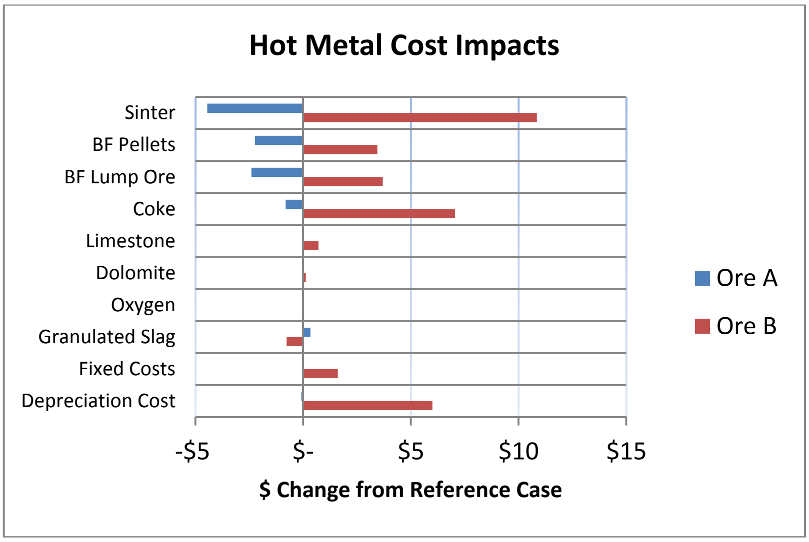

Figure 4: Hot Metal Cost Impacts

In the case of Ore A the results show a net cost reduction due to;

- Reduced ferrous Burden requirements due to the higher Fe content of the Replacement Sinter feed
- Reduced Coke Rate due to lower fuel requirements mainly due to lower gangue contents
- Decreased fixed and depreciation costs per tonne HM due to higher productivity
- In the case of Ore B – a net cost increase due to;
- Increased ferrous Burden requirements due to the lower Fe content of the Replacement Sinter feed
- Increased Coke Rate due to higher fuel rates caused by higher alkaline contents of the ore which increases coke requirements shows the cash cost structures of the reference Case and the two replacement ores.

ISSN 2176-3135

6.7 Comparing the VIU results of Ore A with Ore B

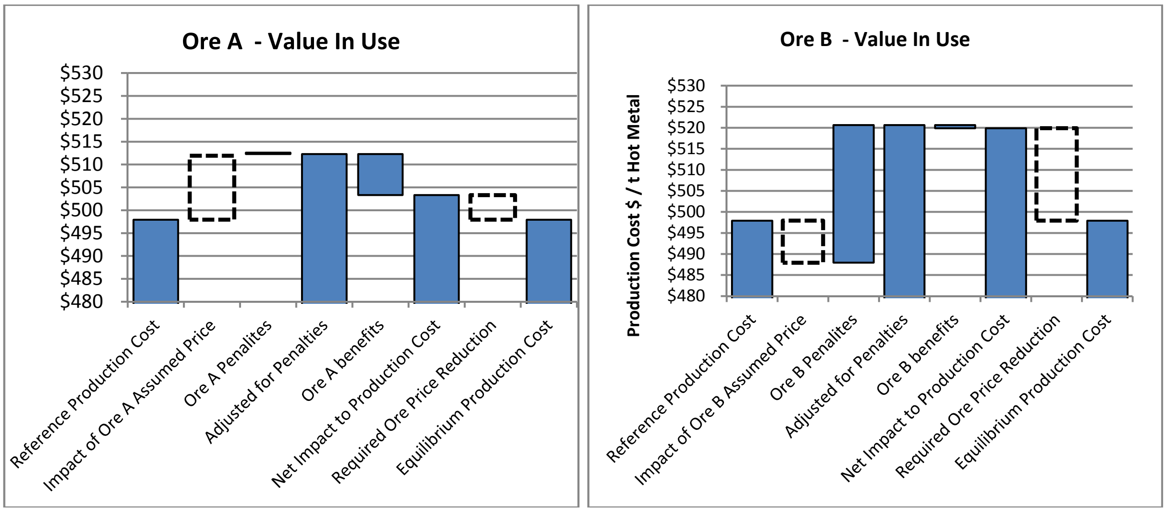

Figure 5: VIU Results Comparison

The VIU modelling results show that for Ore A despite the large cost benefits due to increased productivity the production cost at the assumed higher replacement Ore price is higher than the reference cost and a reduction of $5 / t Sinter Fines is required.

The VIU modelling results show that for Ore B the reduction in cost due to the assumed Ore price is not enough counter the large cost increases due to the loss of productivity. This results in equilibrium Sinter Fine price some $26 / t below the assumed sinter Fines price.

6.8 Sensitivity of VIU to Carbon Price

As the VIU of an Ore is inherently tied to the impacts it's properties have on Furnace Production and the key cost drivers such as productivity and Fuel rates, it stands to reason that in regions where energy efficiency and or GHG regulation measures have been taken that the VIU of an Ore in plants in those regions will be affected.

For the case study we assume the plant is operating in a region where a $20 / t CO2 Carbon pricing mechanism is in place, the impact is high – increasing production costs by approximately $37 / t HM – an 8% increase.

The Direct GHG emission from Iron production (assuming the resultant emissions from BFG use are attributed to Iron Making) are predominately driven by the coke rate and is shown below where for Ore A there is a slight reduction in specific emissions but for Ore B there is a significant increase.

ISSN 2176-3135

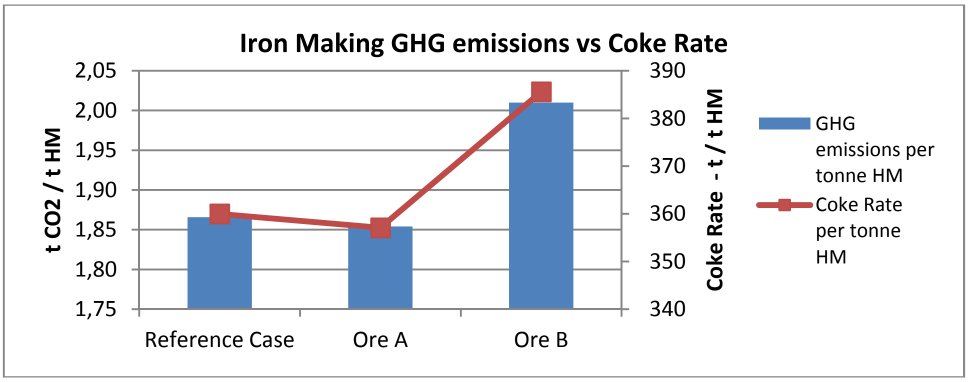

Figure 6: GHG Emissions vs Coke Rate

In the case of Ore A where the coke rate and subsequent CO2 emission drop and induce an additional cost benefit to the steel maker, the Equilibrium Ore Price is higher by approximately $1.60 / t reflecting the additional value in a switch to the better grade ore.

In the case of Ore B where the coke rate and subsequent CO2 emission increase significantly, inducing an additional cost to the steelmaker, the Equilibrium Ore Price is lowered by approximately $3.60 / t.

7 CONCLUSIONS

In order to enable informed ore price negotiations between ore producers and steelmakers, VIU modelling is used to estimate the cost implications of a replacement Ore grade.

In the case study two replacement sinter fine ores were modelled against a reference case in 2 MTPA Blast furnace operations. Ore A presented a higher grade than the reference case and Ore B a much lower grade. The VIU modelling showed the impacts on both variable and fixed operating costs of the replacement Ore's. Ore A showed cost benefit to the steelmaker of approximately $6 / t HM due to a marginal increase in productivity, and lower coke and Fe Burden rates. Ore A showed a significant cost penalty to the steel maker of $24 / t HM due to lower productivity, Higher coke rate due to Alkali loads and higher Fe Burden requirements. Equilibrium prices for the Ore's were then calculated.

The VIU methodology presents a sound way to estimate the net impact ore quality has on carbon costs and the implications for the Value in Use of a particular ore. This was shown where the VIU results were sensitised to a carbon price of $20 / t. For Ore A the production cost impact to the steel maker was reduced through the additional benefit that Ore A reduced GHG emissions whilst Ore B had the opposite effect, increasing production costs further due to increase GHG emissions.