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MYTHS AND REALITIES OF CHARGING DRI/HBI IN ELECTRIC ARC FURNACES*

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Abstract

After almost half a century of experience in using DRI/HBI in electric arc furnaces (EAFs), and taking into account the decrease of natural gas cost in the USA, it is interesting to revisit some trends and controversial issues around this alternative iron source. This paper reviews aspects like the evolution of iron ore quality and its influence on EAF operation; DRI stockpiling and transport, regarding the risk for self-combustion; optimum charge design; cold DRI/HBI charging (fifth hole, bucket, transporter); hot charging (ways and results); carbon content, metallization and silica in DRI/HBI, and its influence on EAF operation and performance; oxygen / carbon balance; chemical energy and DRI/HBI charge.
Keywords: DRI; HBI; EAF; Energy consumption.

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1 INTRODUCTION

1.1 Myth - DRI use Significantly Increases Steel Costs x Reality - Not if Mills Optimize Operations

The production of DRI/HBI has grown almost exponentially since its inception in the early seventies (Figure 1) [1]. In Mexico, Trinidad and Argentina steel mills use DRI supplied by captive plants. In Venezuela DRI is produced for captive steel production and HBI is produced for export. Recently, Venezuelan production has been curtailed significantly leaving world merchant supply lacking. This dearth (and dependence) has renewed interest in DRI/HBI production in the USA where current availability and price evolution of natural gas (NG) has made low cost production of these alternative iron sources (AIS') possible.
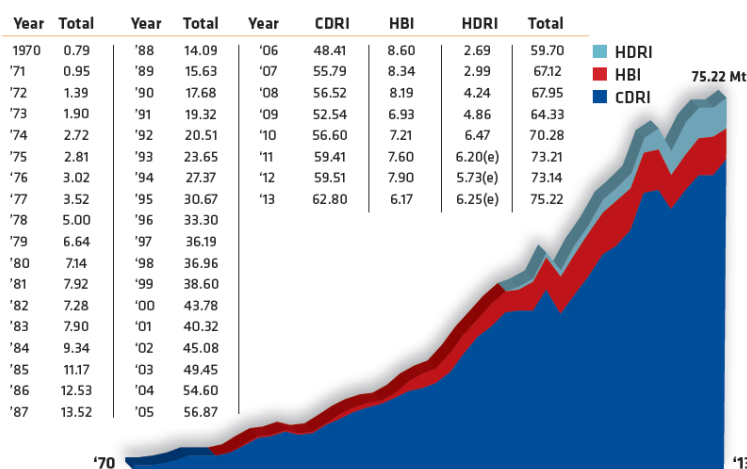
Year	Total	Year	Total	Year	CDRI	HBI	HDRI	Total
1970	0.79	'88	14.09	'06	48.41	8.60	2.69	59.70
'71	0.95	'89	15.63	'07	55.79	8.34	2.99	67.12
'72	1.39	'90	17.68	'08	56.52	8.19	4.24	67.95
'73	1.90	'91	19.32	'09	52.54	6.93	4.86	64.33
'74	2.72	'92	20.51	'10	56.60	7.21	6.47	70.28
'75	2.81	'93	23.65	'11	59.41	7.60	6.20(e)	73.21
'76	3.02	'94	27.37	'12	59.51	7.90	5.73(e)	73.14
'77	3.52	'95	30.67	'13	62.80	6.17	6.25(e)	75.22
'78	5.00	'96	33.30					
'79	6.64	'97	36.19					
'80	7.14	'98	36.96					
'81	7.92	'99	38.60					
'82	7.28	'00	43.78					
'83	7.90	'01	40.32					
'84	9.34	'02	45.08					
'85	11.17	'03	49.45					
'86	12.53	'04	54.60					
'87	13.52	'05	56.87					

Figure 1. World Production of DRI and HBI, 1970-2014 [1].

In this paper, aspects of DRI and HBI production and use, such as iron ore quality, stockpiling and transportation, optimum charge design and charging method, temperature and chemistry of the DRI and HBI, and its influence on EAF operation, energy balance and performance are reviewed. Note: Unless otherwise indicated, DRI is used to refer to both DRI and HBI.

2 EVOLUTION OF IRON ORE QUALITY AND ITS INFLUENCE ON EAF OPERATION

2.1 Myth: Iron Ore Quality is Constant; Reality – It is Diminishing

Most gas-based DRI is produced using pellets as DRI quality lump ore is rarely available. The production of iron ore for pellets usually includes concentration steps to improve quality. Although this has an influence on gangue and phosphorus content, it is not enough to compensate for the decrease in DRI pellet feed quality. The lower quality is related to the over-exploitation of the best iron ore resources during the first 8 years of this century [2].
Besides gangue and phosphorus, sulfur released during pellet reduction is important for those modules that use process gas in the reformer. Furthermore, pelletizing operations may add silica and alumina gangue from the binder and sulfur from the fuel used for induration. Many DRI pellet producers use organic binders instead of bentonite to lower gangue content [3], imbue superior metallurgical and chemical

qualities, hence, improve EAF operations and lower overall steel productions costs. With a higher initial cost than bentonite, the organic binder Peridur can save \$1.81/ton $_{liquid\ steel}$ (t$_{ls}$) and \$1.00/t$_{ls}$ (\$1.65/Tonne$_{ls}$ (Te$_{ls}$) and \$0.91/Te$_{ls}$) respectively for 100% and 50% replacement of bentonite when considering the cost of fluxes, power, yield loss and slag disposal for 94% metallization (Met.) DRI [4]. Miners are attempting to counteract the lower iron ore quality by changing concentration schemes [5,6] and using new approaches to better understand relationships between mineralogy and behavior during pelletizing and reduction [7].

3 RISK OF SELF-COMBUSTION DURING DRI STOCKPILING AND TRANSPORT

3.1 Myth – DRI Cannot be Shipped Distances x Reality – More DRI than HBI is Shipped Today

Despite the known self-combustion (auto-ignition) risks involved in stockpiling and transport of DRI, more DRI than HBI has been shipped annually since 2006: in 2013, 8.56 MTe (9.42Mt) DRI vs. 5.65 MTe (6.22Mt) HBI - Venezuelan HBI shipments to the USA alone decreased from 1.8MTe (1.98Mt) to 0.5MTe (0.55Mt). Generally, DRI is shipped shorter distances than HBI though Acindar and Nucor import DRI from Trinidad. Increased DRI shipments and the need for some plants to stockpile DRI to compensate for winter downtime due to natural gas scarcity, has caused the subject of DRI auto-ignition to be revisited recently [8,9]. Figure 2 shows the merchant DRI and HBI production sites and worldwide trade routes respectively [1,10].
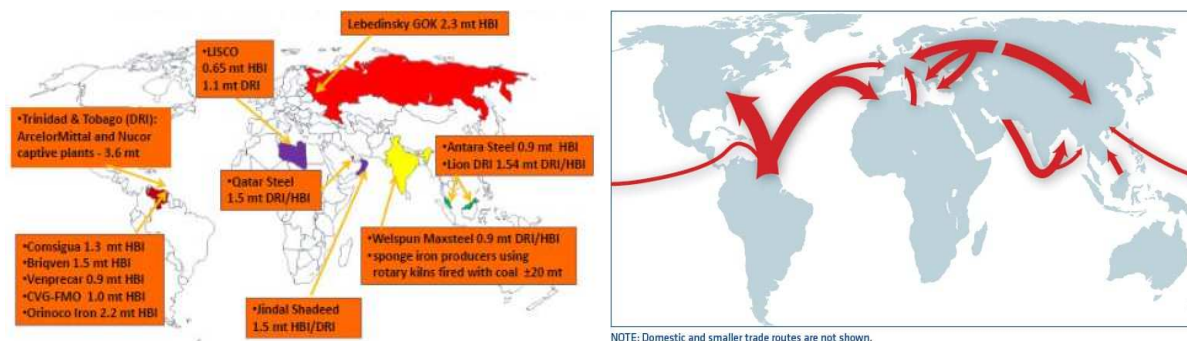

Figure 2. a) Merchant DRI & HBI Production Sites [10]; b) Major Trade Routes for DRI (HBI & CDRI) [1].

Figure 2a shows the worldwide DRI and HBI merchant production reported by the International Iron Metallics Association (IIMA) conference in 2012 [10]. From the total Venezuelan production (6.9MTe; 7.59Mt), this map represents 2008 production [1]. 2013 Venezuelan merchant dropped to 2.8MTe. Figure 2b shows the major trade routes for this merchant DRI/HBI production reported in the worldwide DRI Statistics for year-end 2013 [1]. The width of the lines indicate the amount of DRI/HBI traveling the routes and was drawn from the Iron and Steel Statistics Bureau (ISSB), the Iron Metallics Association (IIMA) and reports from individual operating plants. (Note: 2MTe exported from these plants are not accounted for in the import data [1]). Only Russia and Venezuela typically supply further afield than the regional markets. A well-known example of DRI transportation is from the Nu-Iron plant in Trinidad to USA ports - Charleston, South Carolina, Mobile, Alabama and New Orleans, Louisiana. After discharge at the docks, the product is transported via barges to the receiving mills. Specific procedures are followed for passivation of the DRI in the plant, loading into the ship, inerting of the cargo, and barge transportation etc. [11].

4 CHARGING

4.1 Myth – DRI use Increases Liquid Steel Cost x Reality – Not if Mills use VIU to Define Charge Mixes

4.1.1 Optimum Charge Design [12,13]

Charge mix optimization strategy is very important considering the charge constitutes 73% to 89% of the total cost of liquid steel in an EAF [12]. Historically, mills believed use of DRI/HBI carried an $8 to $30 premium due to the penalties (higher kWh/ton_{ls} (kWh/Te_{ls}), Tap to Tap times (TTT), fluxes, slag FeO content (FeO_{slag}), refractories and electrode wear, yield losses). These increased operating costs predicated DRI EAF use for high quality, low residuals steels' production only. This is true if the EAF operators use DRI/HBI without identifying and understanding the inherent and unique properties and modifying practices accordingly. Educated EAF operators have established standard operating practices (SOPs) that not only negate the preconceived disadvantages, but actually improve operations and operating costs. Table 1 [13] shows use of 50% DRI (composition: 93% Fe $_{total}$, 93% Met., 1.8%C, 1.5% (CaO + MgO), 1.9% (SiO_2 + Al_2O_3), 0.003%S) can reduce $kWh/t_{charged}$ and TTT below that for 100% scrap. Note: these days 93% Met. is considered low and the basicity is now more normally 0.4 to 0.5 vs. the 0. 79 cited in the composition given, especially when operating 60% to 65% DRI.

Table 1. %DRI Impact on Operating Parameters

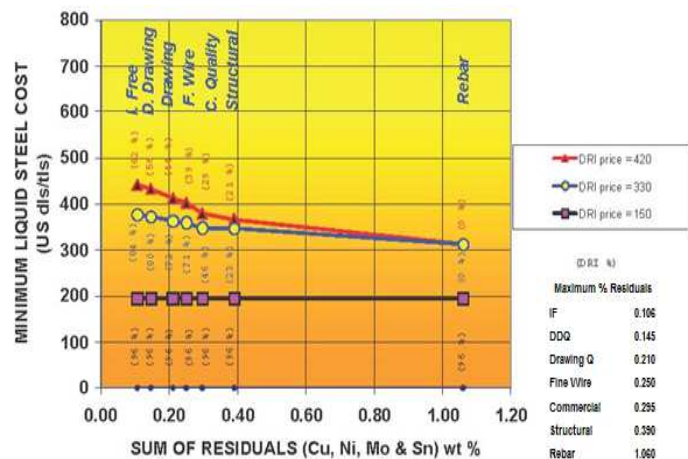| %DRI	kWh/ton	TTT (mins)
All Scrap	421	61
25	375	52
30	377	53
35	380	54
40	393	55
45	399	57
50	408	59

Figure 3. Summary of DRI VIU Results for 7 Steel Grades [12].

To achieve lower operating costs, steel mills must truly understand and quantify their current operating efficiencies, optimize their practices by charge mix and accurately define yield. Cost of variables associated with DRI use need to be quantified - continuous charging, safety and ease of handling (shipping, transfer, sorting, storage, charging...), nitrogen removal capacity, carbon efficiency (contained, in-situ, versus injection or charging - see below), and practice changes needed to accommodate DRI use. Only then will the true value of DRI be revealed. Enter the most important concept for defining optimized charges - the Value in Use (VIU) of metallics.

The VIU balances the raw material's cost, quality, chemistry, yield, charging method (continuous or batch) and temperature with the operational impact of individual metallics on the cost of converting them to liquid steel of the correct composition and quality. Conversion costs include site-specific operational and product chemistry constraints, such as the cost of consumables (power, electrodes, oxygen (O_2),

carbon, natural gas (NG), fluxes, alloys, refractories, stirring plugs, roof life, ancillary equipment), generation and disposal penalty of wastes (slag, dust and yield loss), recovery of metallics, and local metallics supply (material, delivery, storage, inventory, carrying costs etc.), and environmental impact, all of which impact the bottom line. These costs and the costs of constraints will determine the true cost of melting a ton_{ls} (Te_{ls}) [12]. This VIU is site specific and needs to be defined and assigned for each charge material considering the Region (local, national, international) and current economy.

4.1.2 Charging Methodology
As the use of DRI has increased worldwide, charging methods have changed. High %DRI charges abound in captive DRI plants (captive due to poor quality or low availability of scrap - Argentina, MENA) and direct supply to the EAF via a continuous charging system to a 5th hole is available. Invariably there are storage bins or large warehouses to accept DRI supply when the EAF shop is down for maintenance or delays or when stock piling is required for DRI plant shut downs.

4.1.3 Bucket Charging
Bucket Charging is used by steel mills generally using less than 25% to 30% DRI/HBI though it is preferable to continuously charge DRI. DRI/HBI in the bucket aids charge densification as well as lowering residuals in liquid steel. Bucket charging circumvents the cost of a continuous charging system. HBI is usually charged on top of heavy scrap or bundles to maximize densification of the charge and the rest of the bucket is loaded according to the site-specific practice(s) [13,16]. HBI is usually divided between buckets in multiple bucket charges with more in the last bucket to improve the melt refining where the lower %C and increased O_2 content can compensate for lack of O_2 input capacity and minimize blow down at the end of the heat. If a single bucket charge practice is used, HBI is input in multiple layers. HBI tonnage is usually limited to reduce iceberg formation. DRI is charged higher up (third and penultimate layers) in the bucket to prevent DRI falling through the bottom of the bucket.

4.1.4 Fifth Hole (Roof)
Fifth Hole (Roof) charging is preferred for DRI and is definitely more efficient when using more than 30% DRI. Continuous charging facilitates coordination of the feed rate with the power input and flux feeding to ensure slag control (foaming height, viscosity etc.) and prevent ferrobergs which will occur when cold DRI is charged too fast. Continuously charging hot (600°C) DRI can reduce energy required by as much as 16% to 20%.

4.1.5 Side Charging (Consteel [17] or equivalent)
Side Charging is more appropriate for HBI charging and can be combined with continuously feeding DRI through the roof. This set-up has significant benefits over a conventional EAF as the constant flat bath operating condition allows immediate feeding of DRI at a slower rate (less chance of ferrobergs) over a longer period; continuous flux additions control the slag composition more readily; the HBI is pre-heated on the belt as it travels to the EAF.

4.1.6 Continuous versus Batch Charging [12]

Continuous feeding significantly reduces the EAF energy requirement because it affords closed-door operation. This negates heat and time losses from roof swing(s) and charging, not to mention potential nitrogen pick-up arising from air ingress occurring when the roof is open. Table 2, comparing continuous versus batch (bucket) charging, shows continuously charged 33% DRI has the best results, saving 46 kWh/t $_{charged}$ (t_c; 50.6 kWh/Te$_c$) and 4 minutes TTT. Even continuously feeding 43% DRI saves 34kWh/t_c (37.4kWh/Te$_c$) compared to the two (2) bucket charge even though TTT is identical.

Table 2. Continuous vs. Batch Charging of DRI [13,14]

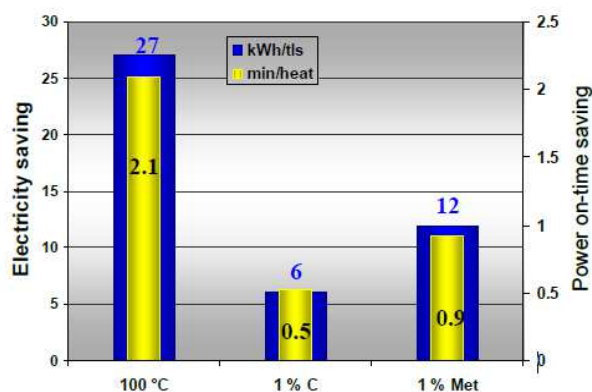|	kWh/t	TTT (mins)
33%DRI – 2 bucket charge	426	58
33%DRI – continuous charge	380	54
43% -= 33% cont., 10% charge	390	55
43%DRI – continuous	392	58

Figure 4. Savings Available from DRI Variations [12].

4.1.7 Cold versus Hot Charging

As previously mentioned hot charging DRI reduces the power requirement by 20kWh to 30kWh/100°C. Figure 4 shows 27kWh/Te$_{ls}$ (24.6 kWh/t$_{ls}$) [12]. Tenova has reported also [17] only 375kWh/Te (340.9kWh/t$_{ls}$) is required to melt 100% DRI with 4%C charged at 600°C using 42Nm^3 O$_2$/Te$_{ls}$ (1377hcf/t$_{ls}$). Preheating DRI to 600°C at Essar [13,14], whilst necessitating a slower DRI feed rate to prevent EAF carbon (C) boils, resulted in power, electrode and TTT savings (124 to 145kWh/Te (112.7 to 131.9kWh/t), 0.3kg electrodes/Te$_{ls}$ (0.6lb electrodes/t$_{ls}$) and 0.06 min./Te$_{HDRI}$ (0.054 min./t$_{HDRI}$). A reduction in DRI FeO content versus their normal HBI production was seen. Combining the AM Mexico cold DRI (CDRI) data (Column 1 and 2, Table 3) with Essar hot DRI (HDRI) results, savings of 191 kWh and $9.27/Tonne (173.7kWh and $8.42/t) are expected when charging 94.4% of 3.1%C DRI at 700°C (column 3, Table 3).

Table 3. Economic* impact of 3.1%C HDRI in an EAF [15]

% Carbon in DRI	2.08%	3.10%	3.10%
Charge %DRI/Scrap (Te$_{DRI}$/Te$_{scrap}$)	94.4 / 5.6 (252 / 15)		
DRI Temperature (^{o}C)	25		700
Scrap Temperature (^{o}C)	25		
% Metallization	95		
% Yield	90		
Power on Time (minutes)	66	57	38.9
Tap to Tap Time (minutes)	80	71	53.9
Total Energy (kWh/Te$_{ls}$)	585.9	527 (-58.9)	419.1 (-191.11)
Productivity (Te/hour)	163	177 (+14)	222 (+59)
Savings @ $0.035/kWh @ $0.050/kWh		4.64 5.53	9.27 12.14

Economics assigned by the authors

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5 CARBON CONTENT, METALLIZATION AND SILICA IN DRI/HBI, AND THEIR INFLUENCE ON EAF OPERATION AND PERFORMANCE

5.1 Myth – DRI is Detrimental to EAF Operations x Reality – Not if SOPs are Optimized

5.1.1 Carbon

High FeO_{slag} increases refractory erosion. Neutralization requires the DRI contain 0.215%C for every 1%Fe as FeO. So, 93% Met. DRI with 93% total iron, theoretically requires 1.4%C for "neutralization". Any excess carbon is available for combustion with oxygen and will reduce electrical energy requirements (4.13 kWh is available from combustion of 1lb C at 100% efficiency (9.09kWh/kg)). The excess carbon promotes also a faster, earlier, foamy slag reaction as FeO_{DRI} melts and CO and/or CO_2 are evolved.

In the early 1990's the majority of steelmakers requested 1.6%C to 1.8%C DRI due to lack of O_2 tools and/or O_2 supply to economically decarburize (deC) the melt. With the advent of more efficient O_2 practices, larger off-gas systems (OGS') and quantification of economics and efficiency of contained (in-situ) carbon, higher %C DRI is used today. In 1999, the average %C in Midrex DRI/HBI was 1.77%C (0.49%C to 2.23%C) and metallization ranged from 91.29% to 96.31%. AM Mexico increased their %C to between 2.5%C and 3.1%C in 1999.

Today, the optimal DRI carbon content is controversial. Some continue to fear the cost impact of iron loss due to carbon replacement thereof versus the cost and energy benefit derived from the in-situ carbon efficiency. Heat transfer to the bath from charged/injected carbon is 25% to 75% efficient, while AM Mexico reports 95% efficiency from DRI in-situ carbon [13,15]. AM Mexico realized modified SOPs were needed when they increased DRI carbon from 2.7% to 3.1% [13]. SOP changes included negation of charge/injected carbon, earlier O_2 use, faster DRI charge rate due to the improved, earlier foamy slag, better heat transfer and bath reactions achieved from in-situ carbon. Table 3 shows the $4.64/Te_{ls} ($4.21/t_{ls}$) is saved when 94.4%DRI is charged and power cost is $0.035/kWh. This carbon efficiency, coupled with the low residual properties, provide benefits such as: economic residual control; lower $[N]_{steel}$ and $[H]_{steel}$ because of improved, earlier, foamy slag and CO purging; reduced energy use, TTT, refractory and electrode wear; increased yield and productivity; lower cost liquid steel (Table 3, Figure 4) [12,15,17].

5.1.2 Metallization

Table 4 shows the benefits derived from a 1% increase in metallization (defined as a percentage of the ratio of metallic to total iron) at Acindar [13,19], Ternium Guerrero [4] and industry in general. Figure 5a and 5b graphically represent the impact at Acindar. Savings of 10 to 25 kWh, 0.425 kg refractories and 0.0375 kg electrodes/Te_{ls} (9.1 to 22.7kWh, 0.85lbs refractories, 0.075lbs electrodes/t_{ls}) with between 0.3% and 2% increase in yield were realized. Increasing metallization from 91% to 95% reduced power 40 kWh/Te (36.4kWh/t) and increased yield 1.5%/1% increase in metallization.

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Table 4. Benefits of a 1% Increase in Metallization of DRI/HBI

Benefits Category	General	Acindar [13]	Ternium Guerrero [4]
KWh/T liquid steel	10 to 25	25	12
Refractory savings/Tonne $_{ls}$	0.425kg	$0.70	
Electrode savings/Tonne $_{ls}$	0.0375kg	0.15kg	
Yield Increase	0.3% to 2%	1%	-4kg/t
Coke savings/Tonne $_{liquid\ steel}$	0 to 4kg	5.8kg	
Productivity Increase	Up to 5%	Up to 5%	
Cost Reduction (VIU)/Tonne$_{ls}$	$0.68 to $2.96	$6.00 to $8.09	$5.00
Increase in Metallization	92% to 93%	93.5% to 94.5%	
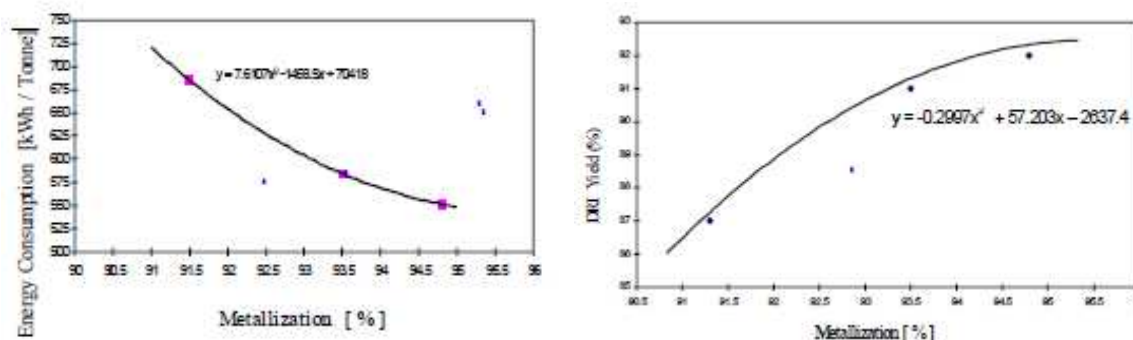
Figure 5. a) kWh/Te vs. Metallization [13,19]; b) DRI Yield vs. Metallization at Acindar [13].

5.1.3 Gangue

The high oxide content in DRI has detrimental process effects. For example a 10% DRI charge requires an additional 15 kWh/Te$_{ls}$, 0.19 kg/Te$_{ls}$ (13.63kWh/t$_{ls}$, 0.38lb/t$_{ls}$), 2.5 mins. TTT, slag former use (hence greater slag volume and disposal cost) and presents a loss of 0.4% yield and productivity. For every 1% decrease in metallization the power requirement increases by between 8kWh/Te and 16kWh/Te (7.3kWh/t to 14.6kWh/t). Contrarily, 10% PI (4% carbon, low oxide) lowers the power requirement by 27.1 kWh/Te$_{ls}$ (24.6kWh/t$_{ls}$).

The scrap "gangue" content can be as high as 10%, when considering low quality obsolete scrap, which contains dirt and other non-metallics. Table 5 shows a comparative analysis of DRI and average scrap at AM Mexico [13]. Increasing the acid gangue content by 1% will increase the basic fluxes (MgO and SiO$_2$) to satisfy the quaternary EAF slag "V" ratio (V$_4$). CaO must increase 2% for each 1% SiO$_2$, but the relationship is exponential (not linear) when SiO$_2$ is higher than 2%. This will increase power requirements by 20 kWh/Te (18.2 kWh/t), as well as increase the slag volume and disposal costs. Table 7 shows additional cost penalties associated with various gangue components in Asian mills as defined by BHP Steel [12,13,15].

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Table 5. Scrap and DRI Compositions at AM Mexico

AM Mexico	Total Fe	%FeO	%C	%Gangue
DRI	90.80	6.77	2.08	4.47
Ave. Scrap	93.85	1.80	0.47	4.25

Table 6. Impact of Excess Combustible Carbon at AM Montreal East

DRI %C	%FeO	92.5% Met	95% Met
1.8%		0.30% C_E	0.75% C_E
2.4%		0.95% C_E	1.45% C_E
2.0%	20%	0.90% C_E	1.45% C_E
2.0%	35%	1.25% C_E	1.75% C_E

Table 7. Cost Associated with Various Gangue Components Defined by BHP for Asian Mills [12-15]

	Cost in US$/Tonne HBI Added to the EAF				
Gangue	+ Fluxes	+ Additions	Yield Loss	Slag Cost	Total
SiO_2 / 0.1%	0.156	0.062	0.135	0.015	0.368
Al_2O_3 / 0.1%	0.114	0.062	0.135	0.015	0.326
CaO / 0.1%	(0.075)	0.030	0.135	0.001	0.091
MgO / 0.1%	(0.071)	0.028	0.135	0.001	0.093

6 CHEMICAL ENERGY APPLIED TO HBI/DRI CHARGE

6.1 Myth – DRI Does not add Chemical Energy to the EAF x Reality – DRI's In-Situ C is a More Efficient Energy Source

The main parameters impacting EAF energy use are composition of raw materials (chemistry, metallization, energy content), operating practices (power profiles, carbon additions, foamy slag and melting practices) and furnace design (heel, O_2 use and tools, Off Gas (OG) and charging systems, AC/DC). Informed, intelligent, DRI use can significantly benefit the operating results, as has been, and will be, seen [15,18]. Chemical energy is usually derived from combustion of carbon (contained, charged or injected), oxygen, natural gas ("fuel" being used) and "burning" elements in the bath (iron (Fe), silicon (Si), aluminum (Al) etc.). Today's new EAF technology and chemical energy tools have increased chemical energy to about 35% of total energy needs, and rising (more than 50% has been seen). This should be maximized if the economics of so doing are beneficial (VIU).

Excess %C in the DRI is available for chemical energy input. AM Montreal East defined this (Table 6) [12]. The in-situ DRI carbon reduces FeO (hence refractory wear) and the kWh/Te$_{ls}$ and increases CO generation (improved foamy slag and arc stability - especially important for the long arc DC operators). This will significantly impact site-specific carbon cost savings, provided mills can capitalize on the high energy. The substantial flat bath conditions are non-conducive to oxy-fuel burner (OFB) use and favor high velocity oxygen lances for rapid decarburization and prevention of delays/penalties in achieving the final carbon.

Greater chemical energy infers increased volume and energy loss to the OGS (nominally 17% to 22% in standard EAFs, 10% in Consteel® and shaft furnaces and 7% in finger shaft furnaces), due to partial combustion. The OGS capacity needs to be sufficient and may need increasing and/or fan operations may need modifying. Optimization is required to capture/retain the maximum amount of energy input. This

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requires understanding the VIU of materials, source of partial combustion, balancing chemical and electrical energy [14,15], and measuring off gas temperatures and composition, in order to maximize combustion and heat retention. Hot charging metallics (solid or liquid) increases the chemical energy input and reduces energy needs significantly. Charging DRI/HBI hot negates the impact of gangue [12]. Hot metal (HM) reduces energy the most but deC (productivity loss) becomes an issue.

7 CONCLUSIONS

7.1 DRI/HBI is here to stay
Myth – DRI/HBI is Used Only Where Scrap Quality is Bad, Availability Low or High Quality Steel Predicates x Reality – Metallics' VIU, Optimization of Charges and SOPs, Lower Cost DRI/HBI Production, Promote Increased Use

Declining iron ore quality is being improved from the mines through to pellet binders. DRI shipped tonnage today exceeds that of HBI. The greater carbon (chemical) energy efficiency of DRI's in-situ carbon can significantly alter the VIU of DRI. Site specific VIU should consider ability to handle high %C (deC tools, OGS), use of low oxide load (gangue) DRI/HBI (organic binders) and (long-term) charge pre-heating to reduce operating costs. As standard operating procedures (SOPs) are altered to accommodate DRI use, the benefits and VIU of DRI will be maximized and detriment to the EAF operations minimized. EAF optimization will be site specific, balancing VIU of DRI and metallics with SOPs. The VIU of DRI burdens changes significantly with price. With the advent of cheap North American shale gas and the drive to invest in new DRI plants, a long term quality metallics supply can be guaranteed. DRI use will be grow as the "price will be right"!. Combining VIU, DRI specific SOPs, educated use of DRI will allow mills to produce low cost liquid steel as effectively as scrap charges.

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