MERITS OF PRODUCING DRI IN AN INTEGRATED STEEL WORKS USING COKE OVEN GAS[1]

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Abstract

Hatch assessed the merits of producing direct reduced iron (DRI) in an integrated steel works using coke oven gas (COG) as a fuel/reductant. A gas-based direct reduction (DR) shaft furnace was added to the traditional integrated steel works flow sheet and the resulting DRI was charged to both the basic oxygen steelmaking furnace (BOF) as a scrap replacement and to the blast furnace to increase productivity and reduce coke consumption. The COG was supplemented with natural gas to increase the amount of DRI produced and scale of the DR furnace facility to make the option more cost competitive. The growing availability of low cost natural gas in North America allows integrated steel producers to consider natural gas as a competitively priced reductant. The merits of adding a dedicated DR plant are described including the impact on the integrated steel works energy balance, the cost to produce hot rolled coil, financial return on the DR plant investment, greenhouse gas and other environmental considerations.

Key words: Cokemaking; Coke oven gas; Blast furnace; Direct reduction.

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1 INTRODUCTION

A traditional integrated steel works uses iron ore and coke to produce hot metal in the blast furnace (BF). Hot metal is subsequently refined into liquid steel in the basic oxygen furnace (BOF) and cast into slabs, rounds, blooms or billets. BOF steelmaking is the principal steelmaking process, accounting for ~70% of global steelmaking capacity.[1] Over the last decade, the cost of iron ore and metallurgical coal has appreciated substantially, raising steelmakers' costs and forcing them to consider alternative process routes. Direct reduction (DR) processes using coal and natural gas (NG) as the reducing agents are available as an alternative to the blast furnace and in 2012 these DR processes represented 5% of global steel production.[2]
Most integrated steel works produce coke oven gas (COG), a high-energy byproduct fuel from the cokemaking process. COG is typically used as a fuel gas for heating applications in different plants within the steel works such as the BF, BOF, casters and reheating furnaces with the balance being used for power production or flared.[3] Burning COG to produce power only recovers 30-40% of the available energy while using the COG as a reducing gas to produce direct reduced iron (DRI) can increase energy recovery substantially. Gas-based shaft reactors typically use reformed natural gas as the reducing gas, but shaft furnaces are capable of using alternative reducing gases such as hydrogen, gases from coal/hydrocarbon gasification, and COG.[4-6] The addition of a DR plant into an integrated steel works can provide iron units to replace scrap at the BOF or to increase blast furnace productivity and lower coke consumption. Regions with competitively priced natural gas such as North America can supplement the available coke oven gas with natural gas to produce additional DRI.

2 CASES ANALYZED

Two cases are presented in this paper; a base case representing a typical North American integrated steel works, and a DRI case that considers the addition of a DR plant – using COG as the reductant – to the flowsheet. The base case assumes a 100% pellet feed and NG injection to the BF with an 80:20 hot metal/scrap charge to the BOF. Tables 1 and 2 show the raw material properties assumed in the analysis.

Table 1. Iron bearing raw material properties

Material	Fe total (%)	SiO_2 (%)
BF Pellets	64.0	3.1
DRI	92.5*	1.8
Scrap	99.5	

** 93% metallization*

Table 2. Carbon bearing raw material properties

Material	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)
Coking Coal	10.5	25.5	64.0
Coke	14.0	0.5	85.5

Table 3 summarizes the energy content and typical uses of gases in the steel works. Figure 1 represents the flow of these plant gases and power to different areas of the integrated steel works.

Table 3. Gas energy content used for analysis

Gas	Energy Content (MJ/Nm^3)	Typical use
Blast Furnace Gas (BFG)	3.5	BF stoves, coke ovens, power plant
Coke Oven Gas (COG)	17.0	Coke ovens, BF stoves, BOF, casters, reheating furnace and power plant
Basic Oxygen Furnace Gas (BOFG)	8.8	Reheating furnaces, power plant
Natural Gas (NG)	36.6	DR reactor, power plant, coke ovens, BF stoves, BOF, casters and reheating furnaces

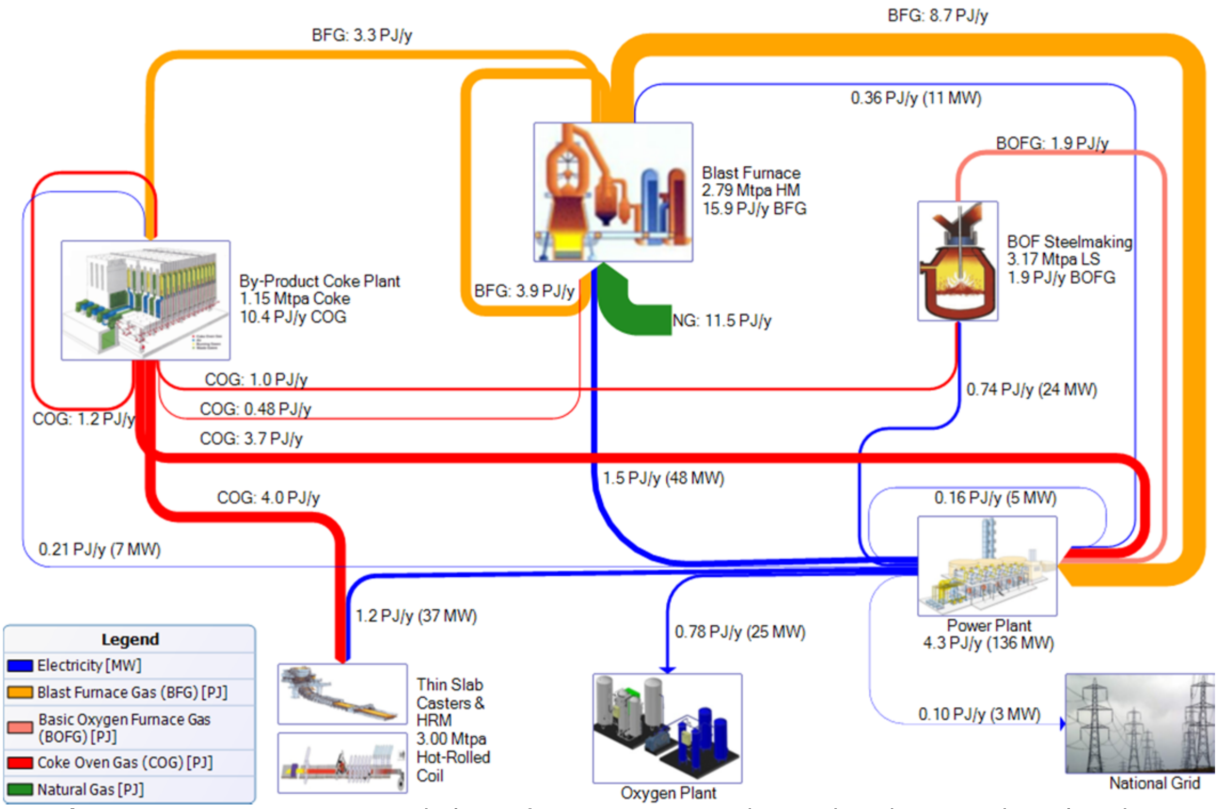

Figure 1. Base Case – Energy balance for a 3.0 Mtpa North American integrated steel works.

For the DRI case, limits were defined for the DRI charge to the blast furnace and BOF. For the blast furnace, a maximum DRI charge of 200 kg/tHM was assumed, as a higher addition of DRI to the blast furnace burden may result in a loss of top gas temperature and needed drying capacity. The BF charge used for each case is summarized in Table 4.

Table 4. Blast furnace burden and fuel rate comparison

Description	**Units**	**Base Case**	**DRI Case**
Burden Composition to BF			
BF Pellets	t/t HM	1.52	1.23
DRI	t/t HM	-	0.20
Fuel use in BF			
Coke rate	kg/t HM	382	347
NG rate	kg/t HM	90	90
Adjusted fuel rate*	kg/t HM	490	455

** Adjusted fuel rate (kg/t HM) = Coke rate + (1.2 x NG rate)*

The addition of DRI to the blast furnace results in increased productivity and decreased coke consumption as shown in Figure 2 for a fixed DRI composition.(7)

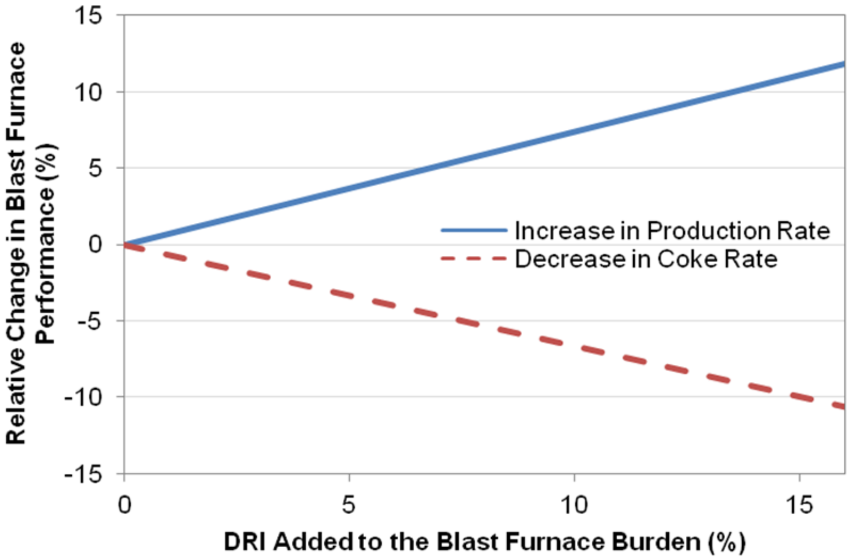

Figure 2. Impact of DRI charged to the blast furnace on productivity and coke rate.(7)

When defining the DRI addition to the BOF, Hatch assumed that all purchased scrap used was replaced with DRI and only home scrap (~50 kg/t LS) was used in the BOF charge mix. The resulting BOF charge for each case is summarized in Table 5; Hatch understands that more DRI can be added to the BOF but this rate was deemed sufficient to represent a typical steel works.(8)

Table 5. Comparison of BOF charge mixes

Description	Units	Base Case	DRI Case
Hot Metal	%	80	75
Scrap	%	20	5
DRI	%	-	20

COG previously used for power generation (3.7 PJ/y in Figure 1) is redirected to DRI production. Adding DRI to the BF reduces coke consumption and increases productivity, reducing the overall coke requirement. The quantity of COG produced and directed toward DRI production is recalculated and amounts to 25-30% of the COG produced by the integrated steel works (Figure 3). BOF gas (BOFG) is also added to the DR furnace as BOFG is an excellent source of CO. The combined COG and BOFG meets the reducing gas quality recommended by Midrex for a shaft furnace, with a H_2:CO ratio of 1.5 and a gas quality – defined as the ratio between H_2+CO and H_2O+CO_2 – of at least 11. The process gas consumption rates for the DRI case are summarized in Table 6; Table 7 shows the properties of the combined COG and BOFG as Midrex quality reducing gas.

Table 6. Required gas volumes and energy content to achieve the Midrex quality target for shaft furnace reformed gas

Gas	Volume (million Nm^3/y)	Energy (TJ/y)
COG	169	2,866
BOFG	95	835
Total	**264**	**3,701**

Table 7. Reducing gas properties of the COG and BOFG mixture used in the DR Plant

Component	**CO**	**CO_2**	**H_2**	**H_2O**	**N_2**
Composition, %	35	7	53	1	4
H_2:CO ratio	1.50				
$\frac{H_2+CO}{H_2O+CO_2}$	12.0				

Based on the maximum DRI capacity calculated from the BF and BOF charge limits defined above (1.46 Mtpa), the shaft furnace requires 14.0 PJ/y of energy, of which COG and BOFG can contribute 3.7 PJ/y. A supplement of 10.3 PJ/y of natural gas is needed to meet the DR plant energy demand. The components of the resulting gas mixture at the DR shaft furnace are shown in Table 8. Hatch assumed that the shaft furnace can operate with the increased gas volume as compared to a standard case where only natural gas is used.

Table 8. Assumed gas mixture to produce 1 tonne of DRI

Gas	**Composition (%)**	**Volume (Nm^3/t DRI)**	**Energy (GJ/t DRI)**
NG	52	194	7.1
COG	31	116	2.0
BOFG	17	65	0.5
Total	**100**	**375**	**9.6**

The resulting change on the steel works energy balance is illustrated in Figure 3, with the production of 1.46 Mtpa of DRI using COG, BOFG and purchased natural gas.

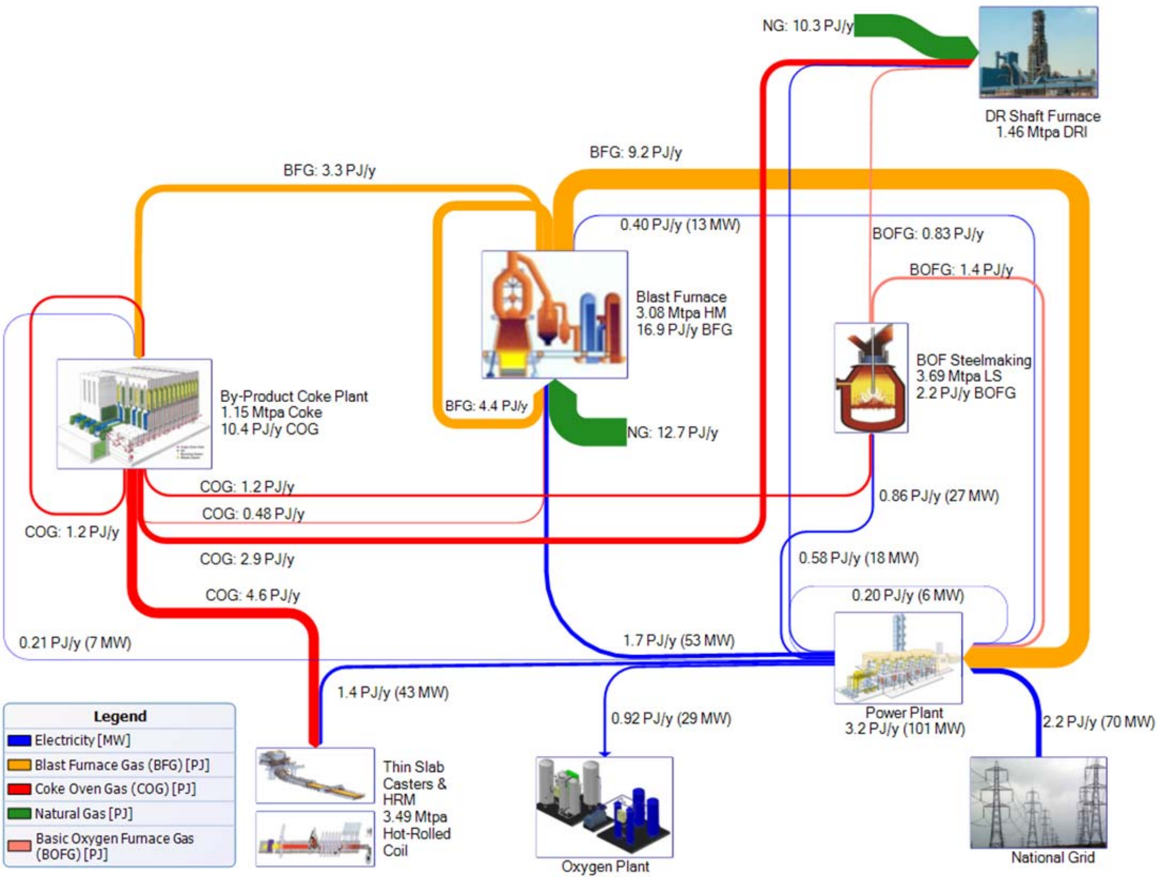

Figure 3. DRI Case – COG, BOFG and NG used to produce 1.46 Mtpa DRI in a 3.0 Mtpa integrated steel works.

Producing DRI on-site and consuming this at the blast furnace and BOF plants increases blast furnace output by 10% and steel output by 16%. A major change to the flowsheet is a new requirement to import 70 MW (175 kWh/t HRC) of electrical power, as opposed to a net export of power for the base case. A summary of the key changes to the integrated steel works flowsheet is provided in Table 9.

Table 9. Summary of key changes to the 3.0 Mtpa integrated steel works flowsheet

Parameter	Units	Base Case	DRI Case	Change
BF production	Mtpa	2.79	3.08	+0.29
HRC production	Mtpa	3.00	3.49	+0.49
Power Import/(Export)	MW	(3)	70	+73
DR shaft furnace capacity	Mtpa	0	1.46	+1.46

3 FINANCIAL ANALYSIS

The cost of producing hot rolled coil (HRC) was calculated based on the assumed costs shown in Table 10 that reflect the late 2012 time period.

Table 10. Cost Inputs

Material	Units	Cost (USD/unit)
BF Pellets	tonne	145
DR Grade Pellets	tonne	160
Scrap	tonne	360
Coking Coal	tonne	180
Natural Gas	GJ	3.5
Electricity	kWh	0.07
Labor rate	labor-hour	65

Assuming that the cost of DRI to the BF and BOF is simply the internal production cost at the on-site DR plant, a comparison of the total costs is provided in Table 11.

Table 11. Operating cost summary

Process Area	Units	Base Case	DRI Case
Ironmaking, BF + de-S station	USD/t HRC	337	320
Steelmaking, BOF	USD/t HRC	143	142
Casting & Rolling	USD/t HRC	36	36
Oxygen Plant	USD/t HRC	14	14
Electrical Power Costs	USD/t HRC	11	15
Total Operating Cost	USD/t HRC	541	527

A breakout of the operating cost difference between the two cases is highlighted in Figure 4. Charging DRI to the BF and BOF reduces metallurgical coal, BF pellet and scrap purchases, while DRI production requires the purchase of DR grade pellets, natural gas, and additional power. A net benefit of USD 14/t HRC for the 3.0 Mtpa hot rolled coil production rate is realized with the DR plant operating within the steel works. For comparison, using only NG to make 1.46 Mtpa of DRI for the BF and BOF results in an operating cost of USD 530/t HRC, providing a net benefit of USD 11/t HRC.

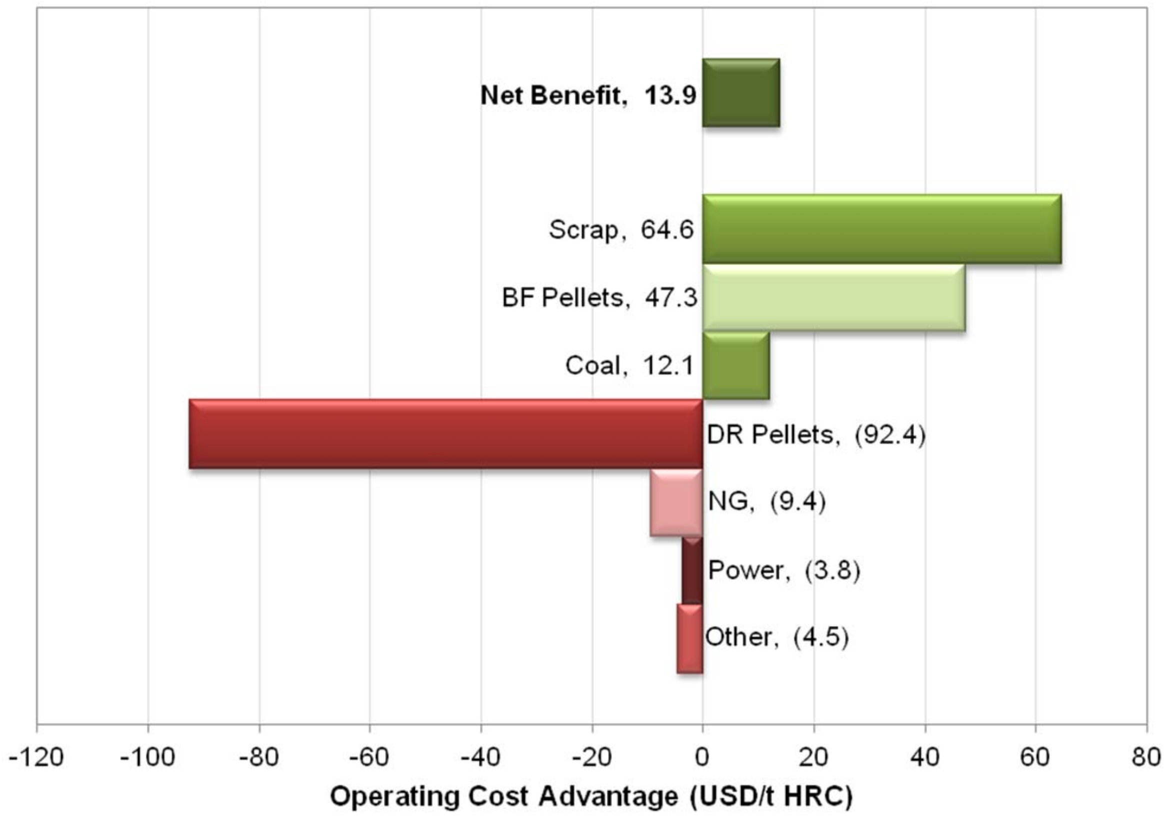

Figure 4. Operating cost advantage when a DRI plant is included in a 3.0 Mtpa integrated steel works.

Hatch calculated the rate of return based on a capital cost estimate of USD 475 million for a 1.46 Mtpa DR plant and a HRC sales price of USD 650/t over a 20-year plant life with a 35% tax rate. The main benefit of the new flowsheet with the DR plant is the increased revenue due to the sale of 16% additional HRC. Results for a sensitivity analysis on the internal rate of return (IRR) with variable raw material pricing are shown in Figure 5.

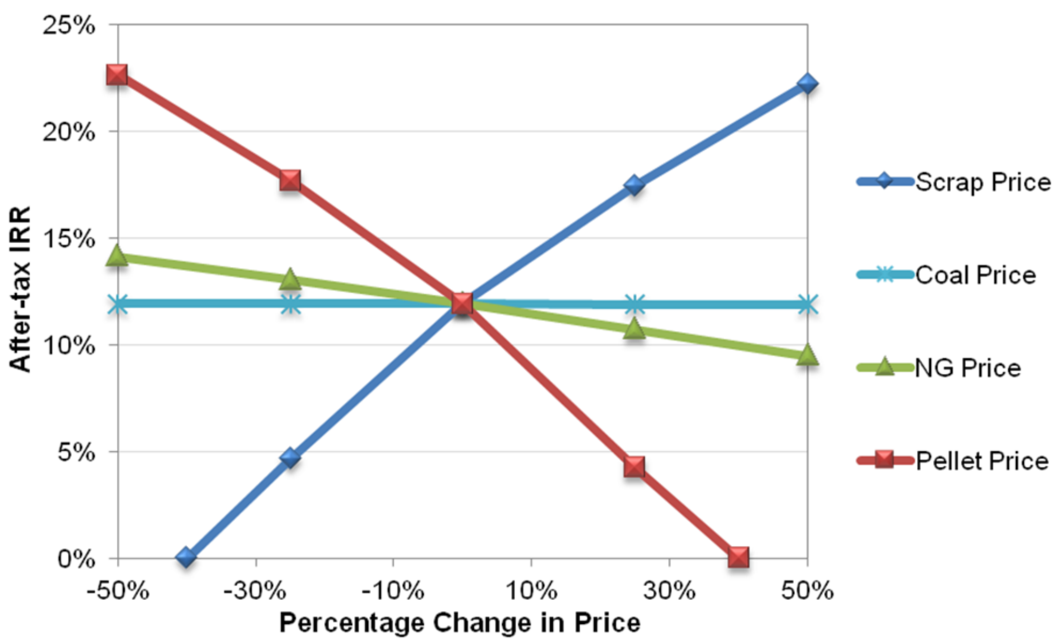

Figure 5. Sensitivity analysis on financial return for the DRI case with varying raw material prices.

The IRR is somewhat insensitive to coal price changes, while higher natural gas prices moderately decreases the rate of return due to the higher cost of making DRI. The DRI case does not require any purchased scrap, allowing steelmakers to insulate themselves from direct scrap market price fluctuations. A decrease in pellet prices makes it more favorable for steelmakers to make DRI rather than melt scrap. If the steel producer owns or is able to control the price of iron ore used to make the DRI, this would also insulate them from iron ore spot market fluctuations, and allows the producer to take advantage of a much higher rate of return due to the lower pellet costs.

4 ENVIRONMENTAL IMPACT ANALYSIS

HRC was used as the basis of an overall steel works' carbon balance to understand the carbon dioxide emissions for the two cases and account for both direct emissions from fuel combustion and indirect CO_2 emissions from off-site electricity generation, as shown in Figure 6. A gas-fired plant is assumed for on-site electricity generation. Figure 7 illustrates the difference between the carbon dioxide emissions for the base case and the DRI case, for both coal-based and hydro-based power grids.

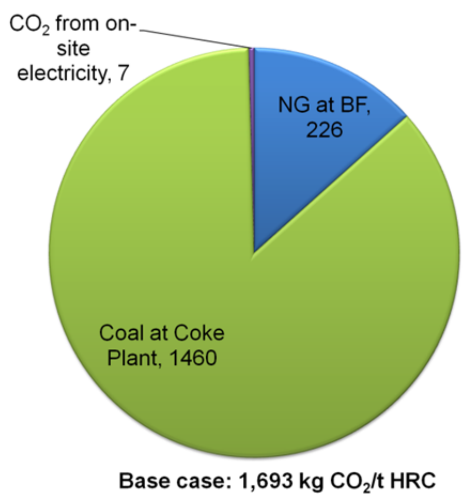

Figure 6. Breakdown of CO_2 emissions for base case (kg/t HRC).

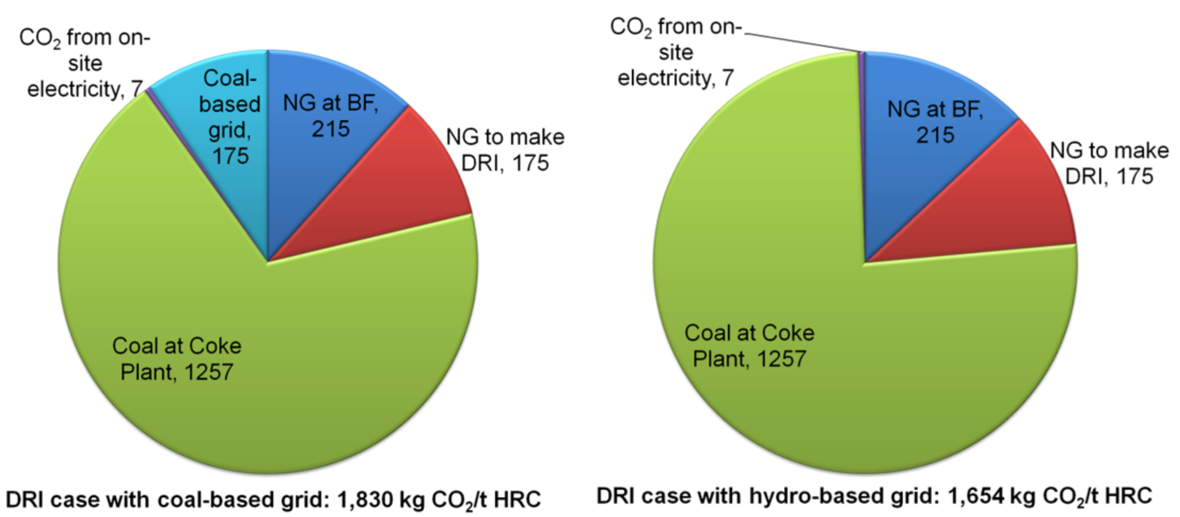

Figure 7. Comparison of CO_2 emissions for DRI case with coal and hydro-based electricity grids (kg/t HRC).

For a carbon-free electricity source such as hydroelectric/nuclear power, the carbon dioxide emissions for the DRI case are 2% lower than the base case. For a grid using coal-fired power plants, the carbon emissions for the case with DRI are higher as the COG is used for ironmaking rather than producing power – necessitating the purchase of power with relatively high CO_2 emissions from the grid. An integrated steel producer in a region utilizing greenhouse-gas-free electricity sources can therefore implement the DR process into their flowsheet and increase productivity with reduction of the carbon footprint of the process per tonne of product. When the grid is based on power generated using natural gas rather than coal, the carbon dioxide emissions for the DRI case reduce from 175 to 82 kg CO_2/t HRC produced (Figure 7, left).

5 SUMMARY

A summary of the cases and key parameters is shown in Table 12.

Table 12. Summary of cases

Description	Units	Base Case	DRI Case
Blast furnace production	Mtpa	2.79	3.08
Coke plant production	Mtpa	1.15	1.15
Liquid steel production	Mtpa	3.17	3.69
HRC production	Mtpa	3.00	3.49
DRI Production	Mtpa	-	1.46
Total scrap purchased	Mtpa	0.54	-
Electricity purchased	MW	(3)	70
Operating cost	USD/t HRC	541	527
CO_2 emissions (hydro/nuclear power)	kg CO_2/t HRC	1,693	1,654
CO_2 emissions (natural gas based power)	kg CO_2/t HRC	1,693	1,737
CO_2 emissions (coal based power)	kg CO_2/t HRC	1,693	1,830

The production and consumption of DRI in an integrated steel works flowsheet can potentially increase HRC production by 16% and reduced operating costs by USD 14/t HRC, resulting in an after-tax IRR of 12%. Using COG and NG as reductants to produce DRI eliminates scrap purchases, allowing steelmakers to insulate themselves from scrap market price fluctuations. The financial returns for on-site DRI production increase substantially if the steel producer has access to low cost iron ore.

Using COG to produce DRI necessitates more purchased power, an attractive arrangement in regions where electricity is cheap, green and readily available. If the grid uses a carbon neutral power source, the steel works can increase production with a reduction to its carbon footprint.

The decision by steelmakers to adopt the use of COG as an alternative reducing gas must consider the operating cost advantage, and capital cost required to install the necessary equipment, along with land availability and pipe rerouting considerations. As most steel works are more complex than that presented in this paper, a detailed assessment of the merits of DRI production must be made considering the local conditions to define this cost reduction opportunity.

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REFERENCES

1 World Steel Capacity Utilization. World Steel Association 2013. www.worldsteel.org
2 Iron Production Statistics. World Steel Association 2012. www.worldsteel.org
3 Metius, G., “Coke Oven Gas Options for Direct Reduction”. Direct from Midrex Q4 2012. www.midrex.com
4 Technical information about Reducing Gas Properties, available at Midrex website: www.midrex.com
5 Worberg, R. Cokemaking – highlights and market trends. 2011, Dusseldorf, Germany. METEC InsteelCon – Plenary Session 6th ECIC
6 Deimer, P.; Bodo Lungen H.; Reinke, M.; Utilization of Coke Oven Gas for the Production of DRI. 2011, Dusseldorf, Germany. METEC InSteelCon – Session 3
7 Ostrowski, E.; Stephenson RL.; Kercsmar, DA.; Use of DRI in Ironmaking. [ed.] Feinman J. and Mac Rae DR. Direct Reduced Iron – Technology and Economics of Production and Use. Warrendale. The Iron and Steel Society, 1999, pp. 147-157
8 Pastucha, K. et al. Steel Quality Improvement with Use of HBI Briquettes at the New Greenfield LD Steelmaking Plant AMK Alchevsk, Ukraine. St Louis, MO, USA. AISTech 2009 Proceedings – Volume II, pp 1013-1022