ENERGIRON HYL

THE INNOVATIVE DIRECT REDUCTION TECHNOLOGY

ENERGIRON Technology
General Overview

August, 2012

The New Generation Of Direct Reduction Technology And Steelmaking Integration

ENERGIRON

- ENERGIRON is the trademark of the innovative direct reduction technology jointly developed by the Tenova HYL and Danieli alliance. Pioneering in direct reduction since the 1950s with the WORLD'S FIRST INDUSTRIAL PLANT in 1957.
- ENERGIRON Direct Reduction technology can be integrated with steel making technology via HYTEMP®, the hot DRI transport system, providing additional benefits in terms of energy savings, metallic yield and environmental impact.
- ENERGIRON Direct Reduction technology can also be integrated with Blast Furnace technology through the use of Coke Oven Gas as DR process gas, giving a significant added value to the Blast Furnace operation.
- ENERGIRON Direct Reduction is the most effective technology in terms of environmental impact, with extremely low pollution, NO_x and CO_2 emissions.

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Keying the Technology to the Market

- For the DRI market, our technology advances have made us the perfect choice for the new market conditions in terms of virgin iron supply:

  ✓PROCESS: Simpler, same scheme for all energy sources available, smaller in size yet larger in capacity than any competing technology.

  ✓PRODUCT QUALITY: Unique DRI quality: hot or cold discharge with 94-96% Metallization and Carbon ~4%.

  ✓ENVIRONMENTAL IMPACT: Lowest NOx, and selective elimination of CO_2 as integral system to our technology, with lucrative by-product options (currently commercialized in various DRP's), makes ENERGIRON the greenest option.

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Keying the Technology to the Market

- ✓EFFICIENCY: The ENERGIRON ZR scheme is the most energy efficient in the market.
- ✓The overall efficiency of the ZR scheme (83-87% vs. 75% of others) can be noticed when making a benchmarking comparison:

Energy Efficiency of DR Processes				
		Other DR Technology [1]	ENERGIRON ZR Technology	ENERGIRON ZR Technology (Non-selective Carbon-free
Product Quality	Metallisation Carbon	93% 2.0%	94% 3.6%	94% 3.6%
Energy Consumption	Nat. Gas (Gcal/t) Electricity + Oxygen injection (kWh/t)	2.35 110	2.30 70	2.30 100
CO_2 selective removal	Included as energy savings (Gcal/t)	No 0	Yes (60% of CO_2 emissions) -0.20	Yes (90% of CO_2 emissions) -0.28

[1] based on published data available

- ➢ Higher DRI Energy content;
  94%Mtz; high-C DRI (≥ 3.5%C)
- ➢ High DRI temperature
- ➢ Selective CO_2 removal

For just 2.3 Gcal/t DRI !!!!

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Why ENERGIRON Technology?

- Flexibility
- Economy
- Environmentally sound
- Trend
- Quality iron for quality steel: DRI Value

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ENERGIRON ZR: Flexibility

Flexibility for using different sources of Reducing gases with the **SAME Basic Scheme**

Selective removal of oxidants **(H_2O & CO_2)**: Energy Optimisation & **CO_2** as by-product

Minimum iron ore losses in top gas: <1%

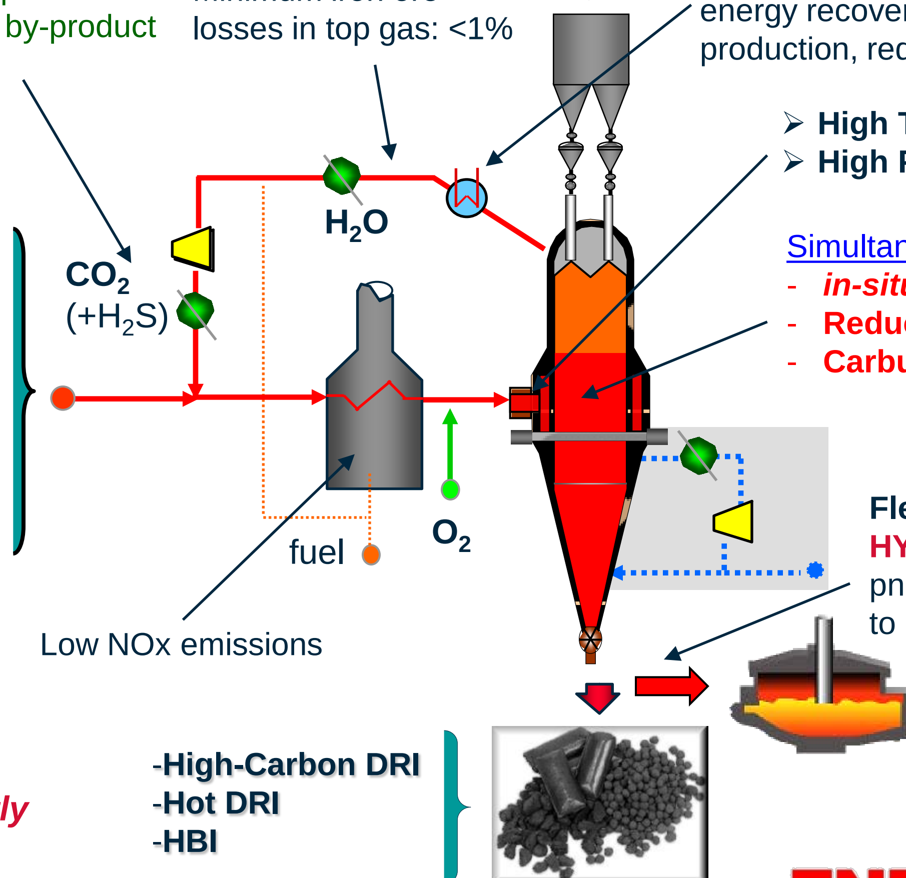
Wide range of raw material quality (Sulphur in Iron Ore is not a limitation)

Overall energy integration (waste energy recovery for steam production, required for CO_2 removal)

- **High Temp: >1050°C**
- **High Pressure: 6-8 bar**

Simultaneous:
- ***in-situ* CH_4 reforming**
- **Reduction of iron ore**
- **Carburisation**

Reducing gases sources
- **Natural Gas**
- **Reformed Gas**
- **Coal Gasification**
- **COG**
- **others**



Flexibility to process any Natural gas quality

Low NOx emissions

Flexible, reliable and safe HYTEMP System to pneumatically transport DRI to EAF's

DRI with Metallisation≥94% and 1.5%-4% Carbon, mostly as Fe_3C (>90%)

- **-High-Carbon DRI**
- **-Hot DRI**
- **-HBI**

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ENERGIRON ZR Technology

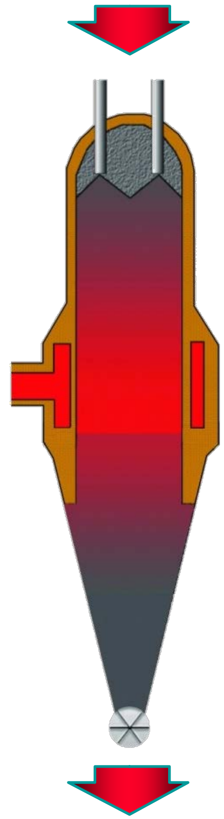
Features: "In-situ" Reforming and Reduction

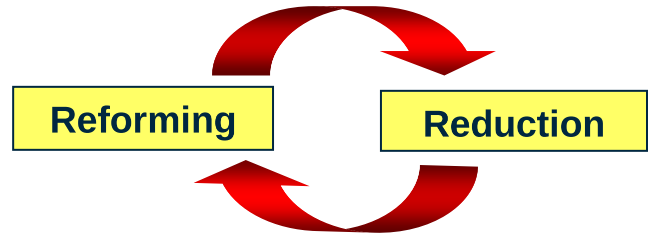
IN-SITU Reforming:

- *Conditions for Hydrocarbons reforming:*
  - presence of Oxidants and hydrocarbons (H2O+CO2 +CnH2n+2)
  - high temperature
  - presence of catalyst

Iron Oxides Reduction:

- *The conditions for the reduction of iron oxides are:*
  - presence of reductants
  - (H2+CO)/(H2O+CO2)>>1
  - high temperature
  - presence of iron oxides





In-situ Reforming

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$CH_4 + CO_2 \longrightarrow 2CO + 2H_2$$

Reduction

$$Fe_2O_3 + 3CO \longrightarrow 2Fe^{\circ} + 3CO_2$$

$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe^{\circ} + 3H_2O$$

Carburization

$$3Fe^{\circ} + CH_4 \longrightarrow Fe_3C + 2H_2$$

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ENERGIRON DR Plant: Module sizes

Emirates Steel Industries (GHC)
1.6 mio tpa Hot/Cold DRI

Standard Modules

Capacity (Mt/year)		Reactor size (approx. nominal ID- m)
200,000	(Micro-Module)	2.5
500,000		4.0
800,000		5.0
1,200,000		5.5
1,600,000		5.7
2,000,000		6.0
2,500,000		6.5

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Sized to Compete With Integrated Iron Production

Two plants at 1.6 and seven plants from 1.9 to 2.5 million tons each, using both Natural Gas and Syngas/COG.

Client	Country	Mtpy
Welspun Maxsteel Ltd. 2	India	0.60
Emirates Steel I (revamp project)	UAE	1.60 → 2.0
Gulf Sponge Iron	UAE	0.20
Emirates Steel II (revamp project)	UAE	1.60 → 2.0
Sidor	Venezuela	0.80
Ezz Rolling Mills	Egypt	1.90
Suez Steel	Egypt	1.95
Taichin	China	0.50
PT Krakatau expansion	Indonesia	0.75
Nucor Steel	USA	2.50
JSPL (4 plants committed @ 2.50; 1-contracted/Eng.)	India	2.50 x 4

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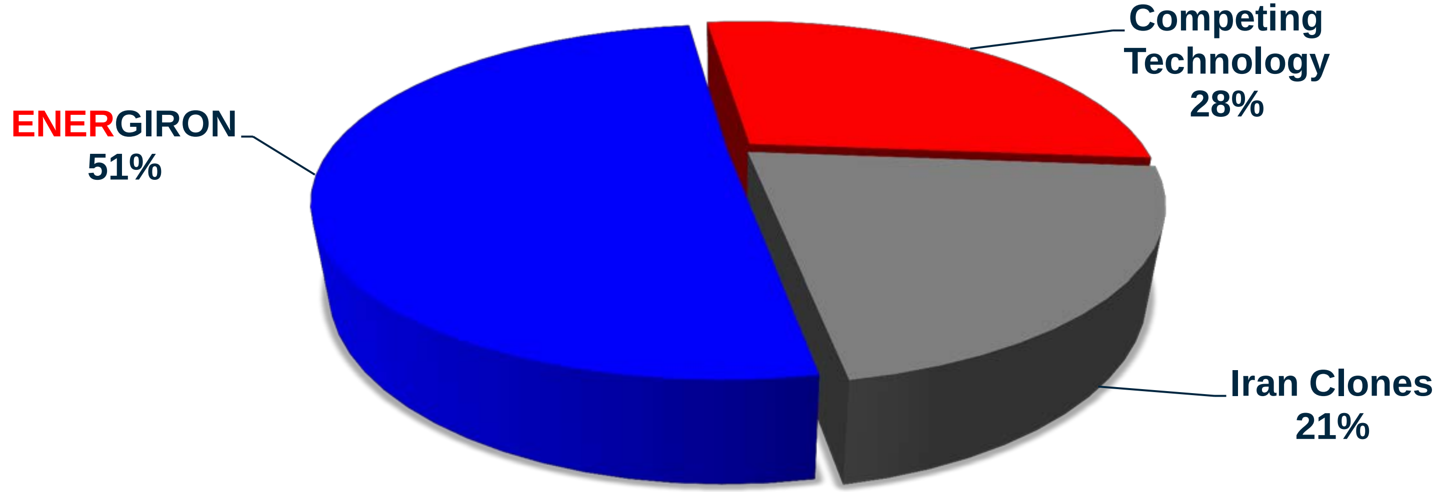
DR Market Preference Change in Recent Years

New DR Plants Contracts since 2006
Gas-based DR technologies



Based on tpy contracted capacity

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Gulf Sponge Iron, Abu Dhabi

- First ENERGIRON Micromodule
- 200,000 tpa
- ZR plant for high carbon DRI
- Started up 2010

- Ideal for small steel producers due to low cost natural gas supply

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Emirates Steel I and II, Abu Dhabi

- Twin plants
  - 1.6 mtpa nominal capacity each
  - Both use HYTEMP System to meltshop
  - Module I started 2009
  - Module II started 2010
  - Project underway to increase capacity to 2.0 mtpa each, for 4 mtpa total capacity

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Ezz RMS and Suez Steel, Egypt

- Suez Steel-Egypt
  - ENERGIRON ZR scheme
  - 1.95 mtpa nominal capacity
    - 94% Mtz; 3.5% Carbon
  - HYTEMP System to meltshop
  - Start-up scheduled end 2012

- Ezz Rolling Mill Steel-Egypt
  - 1.90 mtpa nominal capacity
  - Cold, high-Carbon DRI
    - 93% Mtz; >3% Carbon
  - Start-up scheduled: pending

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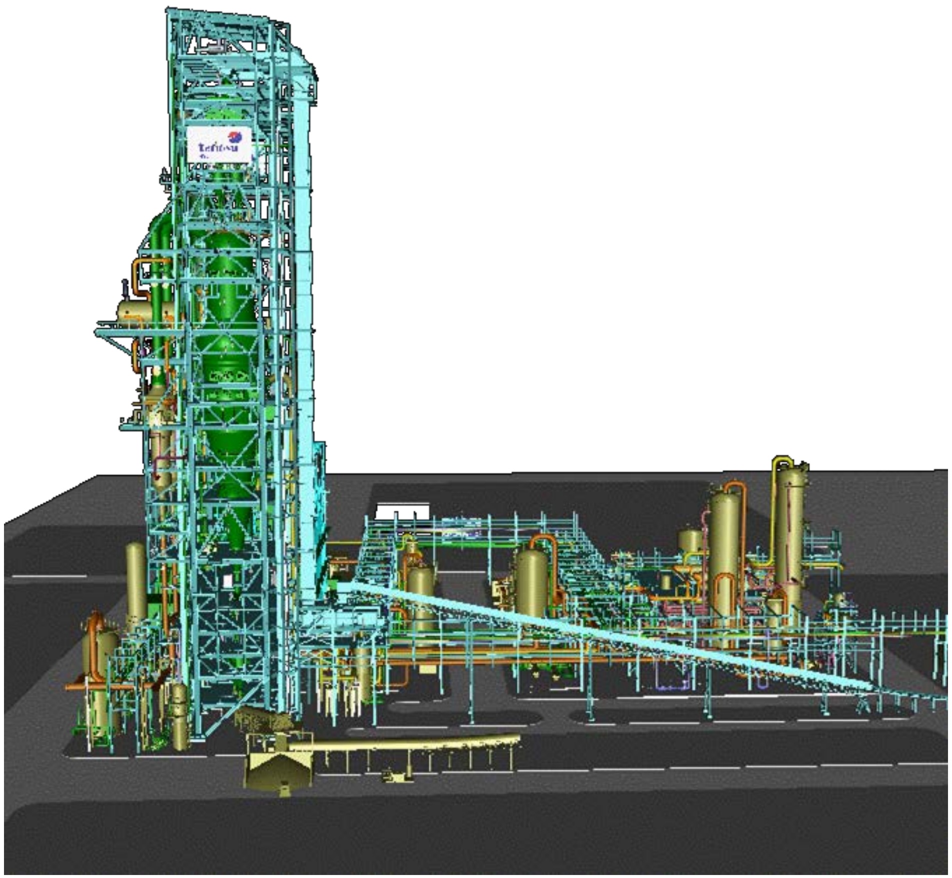
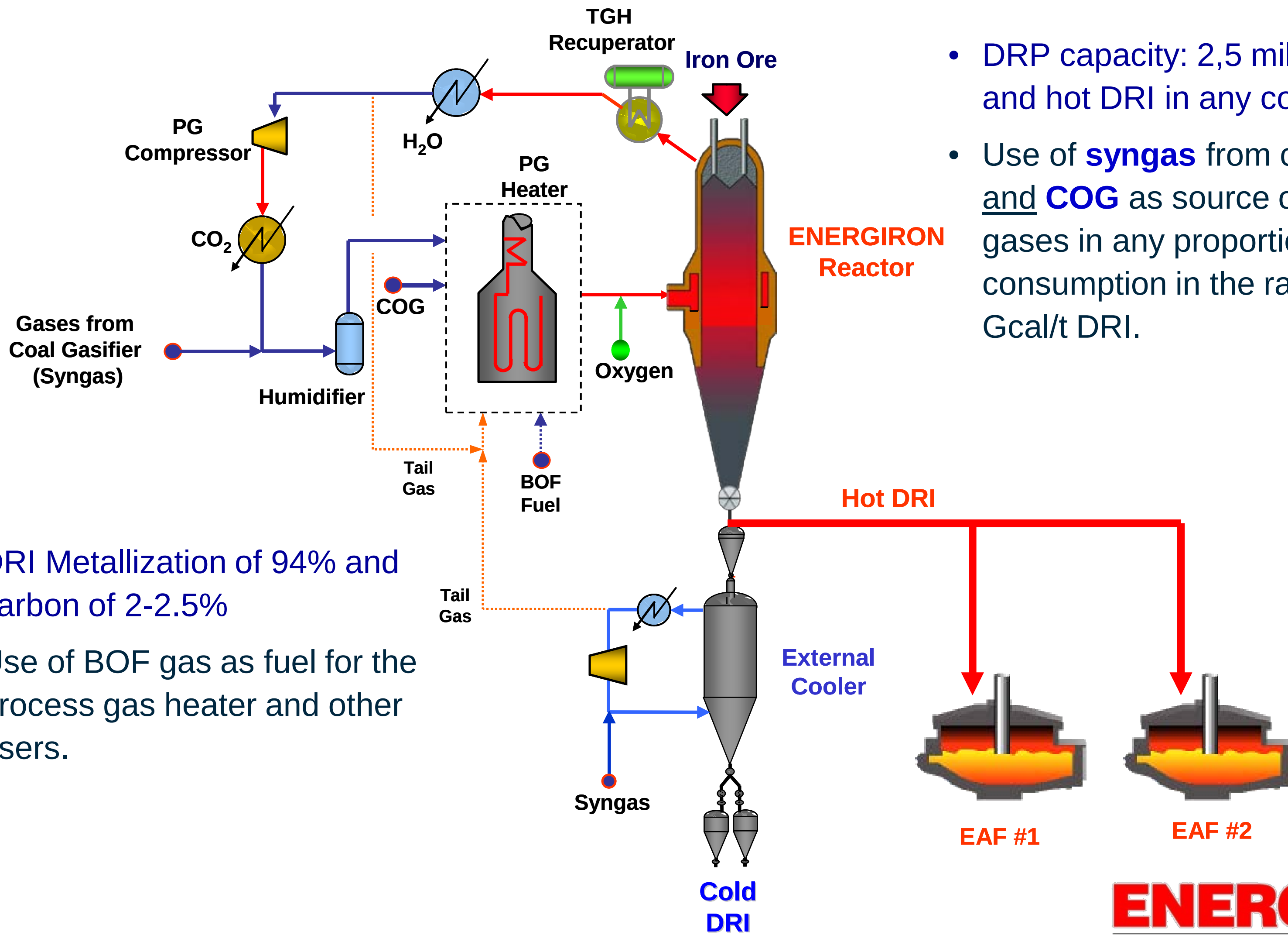
Nucor Steel Louisiana, USA



- World's largest single DR module under construction
  - 2.5 million tpy capacity
  - ENERGIRON ZR scheme
  - 96% metallization
  - ≥ 3.0% carbon
- Startup set for 2013

JSPL DR Project

Tenova HYL together with Danieli & C. signed a contract for the first of four ENERGIRON DR plants for Jindal Steel & Power of India. Main characteristics:



- DRP capacity: 2,5 million tpa of cold and hot DRI in any combination.
- Use of **syngas** from coal gasification and **COG** as source of reducing gases in any proportion, with energy consumption in the range of 2.2 Gcal/t DRI.

- DRI Metallization of 94% and carbon of 2-2.5%
- Use of BOF gas as fuel for the process gas heater and other users.

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ENERGIRON DR Technology: Consumption figures

ENERGIRON ZERO REFORMER (ZR) PROCESS		
Metallization Carbon Temperature	% % ºC	94 2.5 600 (at EAF)
	Unit	Consumption Unit/t DRI
Iron ore pellets / lump ore*	t	1.38**
Natural gas	Gcal	2.38
Oxygen	Nm^3	54
Nitrogen	Nm^3	22
Electricity Core Area + Mat. Hand.	kWh	77
Electricity Aux. Plants	kWh	13
Water	m^3	1.2***
Labour	m-h	0.15

* Lump ore up to 30% can be used without affecting productivity

** after screening

*** if closed circuit with sea water cooling, the plant is a net water producer

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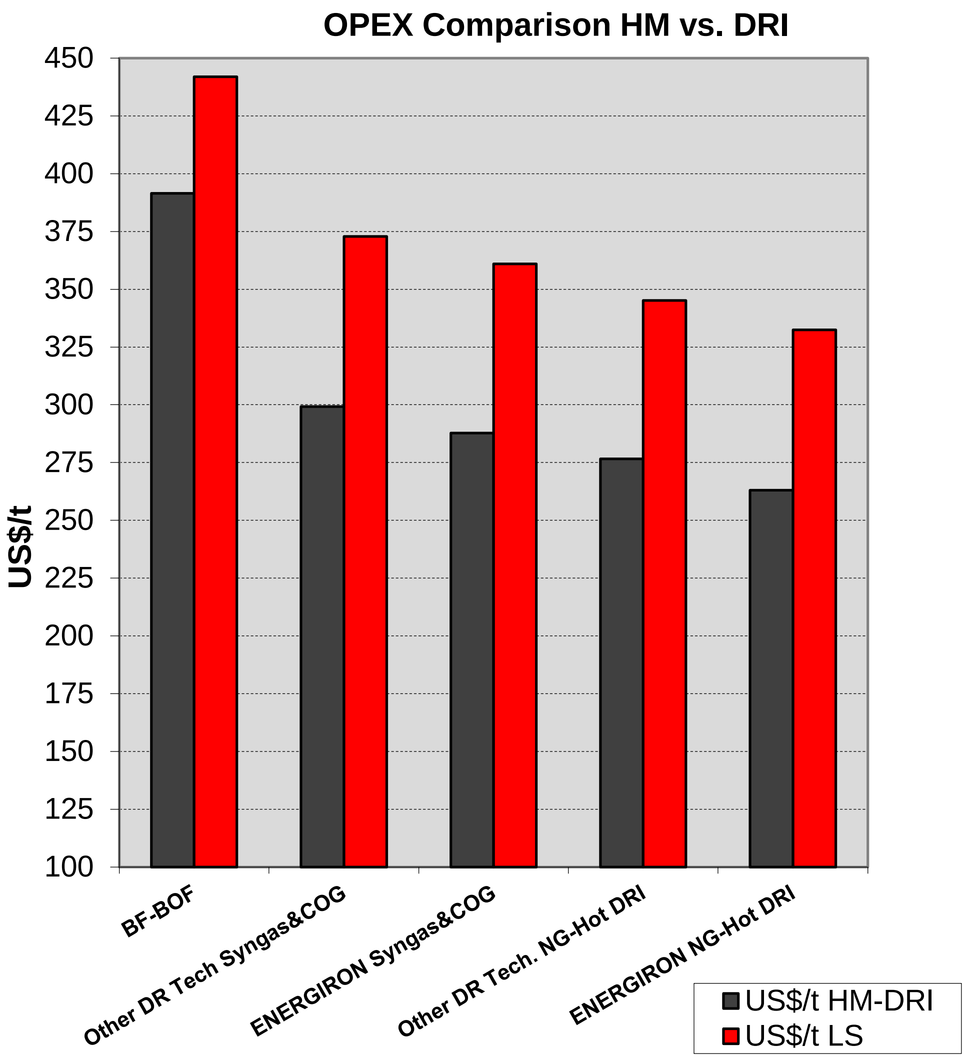
ENERGIRON DR : OPEX estimate



In general due to lower NG cost, the DR route offers a much lower OPEX as compared to HM production.

When compared to other DR process, the ENERGIRON ZR presents OPEX benefits for EAF steel production, basically due to:

- Overall lower Energy consumption in terms of NG and power*,
- Less fines losses= less ore consumption*,
- Higher benefits in EAF due to High-Carbon DRI,

** Due to high-pressure operation*

Oper. figures based on published data,
NG @$3/MMBTU,
Iron ore @$160/t;
all others int. prices

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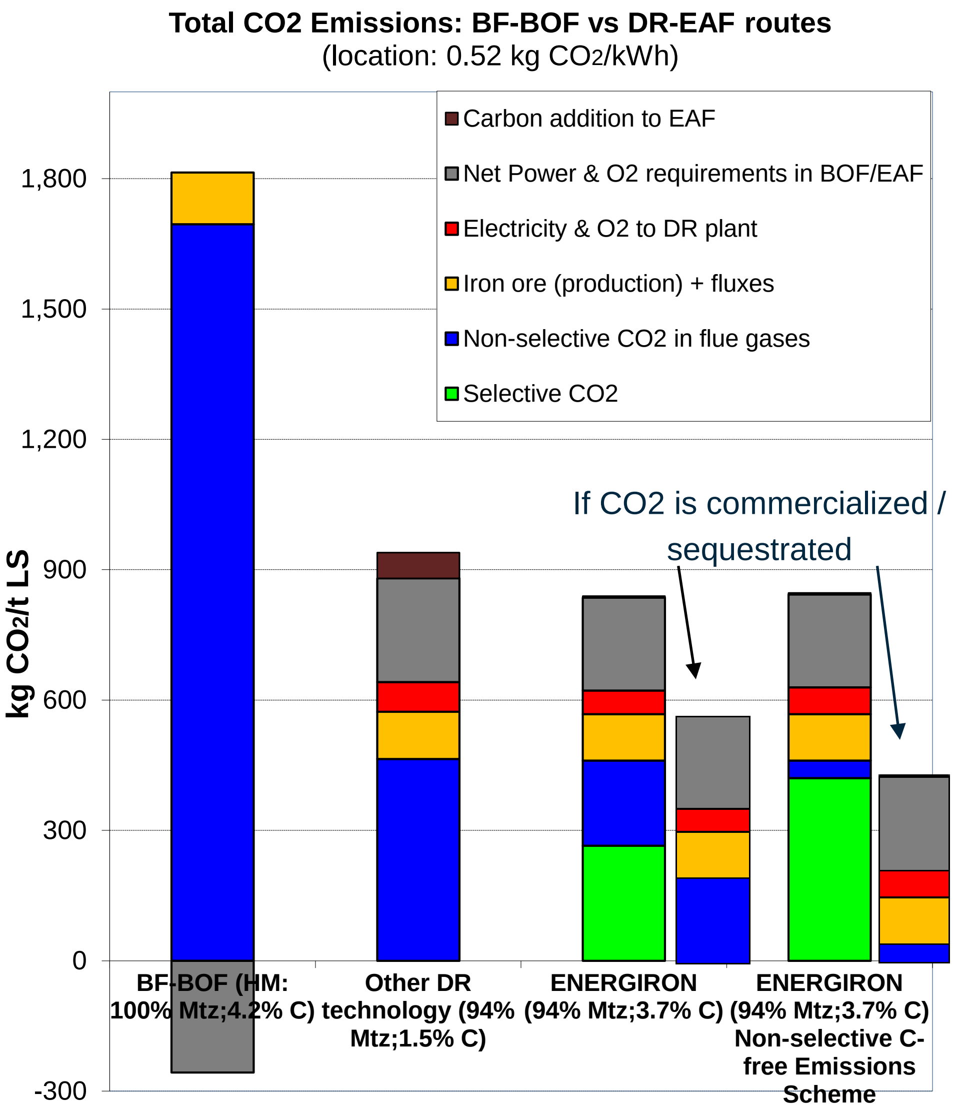
ENERGIRON DR: Environmentally sound



- CO_2 Emissions:
  - There is an implicit difference in terms of CO_2 emissions between BF-BOF and DR-EAF routes simply because of the nature of the primary energy being used: NG vs. Coal.
  - While other DR schemes configurations simply vent non-selective CO_2 through the flue gases, the ENERGIRON process-based DR plants selectively remove CO_2.
- *For NOx Emissions, the ENERGIRON ZR technology is of only 25 ppmV without the need of specific/additional equipment.*

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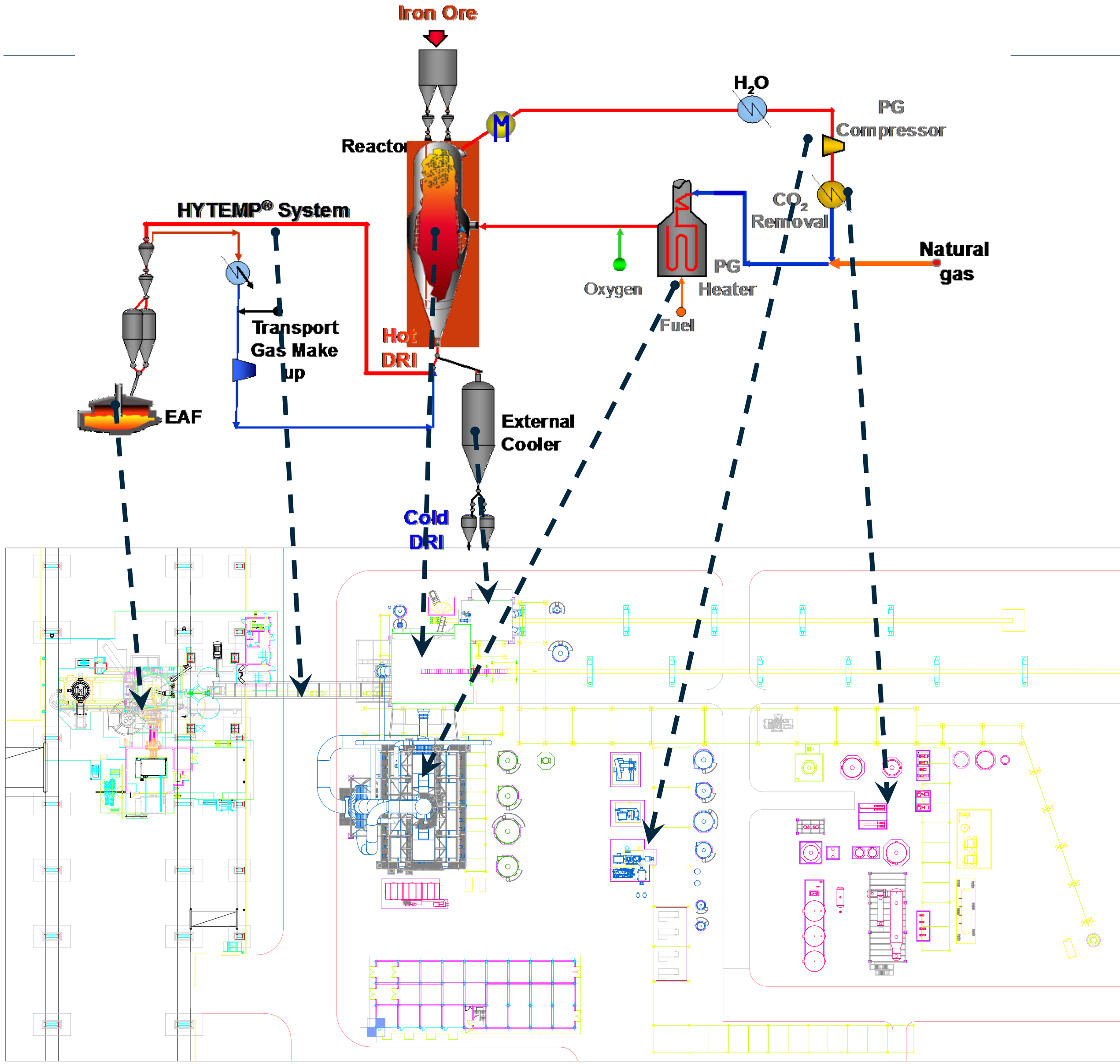
DRP Integration with Meltshop

Scheme:	ZR with HYTEMP
Production rate:	250 t/h
	Cold/Hot DRI
Equivalent to:	2'000,000 t/a
DRI quality:	94% Mtz
	3.5% C
DRI temp. @ EAF:	≥ 600°C

Layout for ENERGIRON ZR



- \> For 2,000,000 tpy
- \> Hot and Cold DRI production
- \> HYTEMP (Pneumatic transport) to Meltshop
- \> Footprint Core area: ~ 160m × 100m
- \> Footprint including stockyards and auxiliaries: ~ 350m × 330m
- \> DR Reactor: 6.0 m ID
- \> Heater:~ 440,000 Nm^3/h ≥ 970°C

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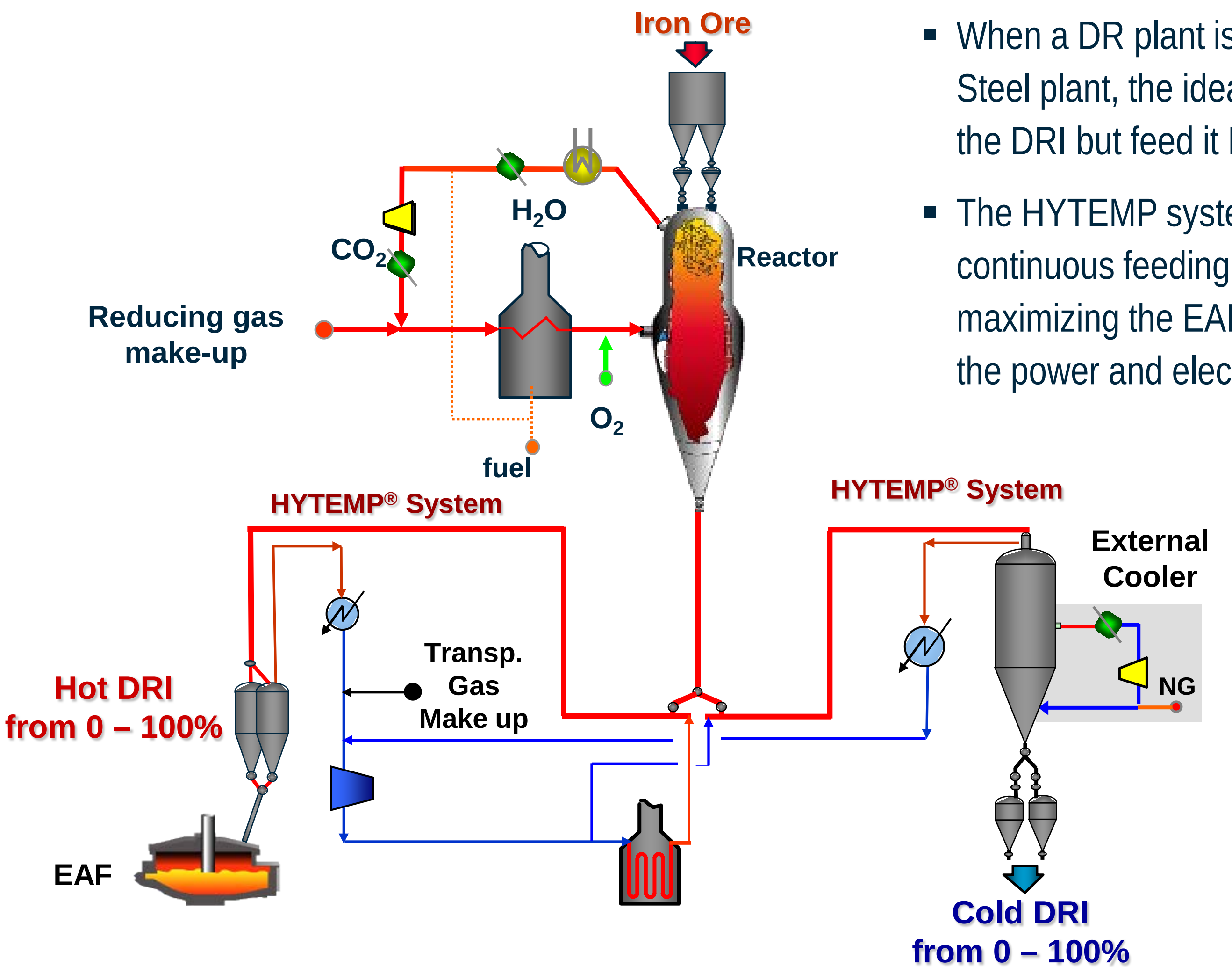
HYTEMP® System

ENERGIRON DR Technology
Scheme with HYTEMP® System for Hot DRI transport



- When a DR plant is located inside an integrated Steel plant, the ideal condition is not to cool down the DRI but feed it Hot to the EAF.
- The HYTEMP system takes full advantage of the continuous feeding of Hot DRI to an EAF maximizing the EAF productivity and minimizing the power and electrodes consumption.

Typical annual production ratio hot DRI/cold DRI: 90-95%/10-5%

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ENERGIRON DR Technology

Scheme with HYTEMP® System for Hot DRI transport

- Pneumatic transport; totally enclosed
- Flexible for feeding >1 EAF; no layout restrictions
- No effect on DRI quality; carrier inert gas
- Distance up to 400-500m

- Fully automated and integrated system
- No wearing parts and almost maintenance-free
- Minimum heat losses (~80°C)
- N_2 make-up: 5-8 Nm3/t
- Power consumption: 3-6 kWh/t
- Compliance with all safety regulations

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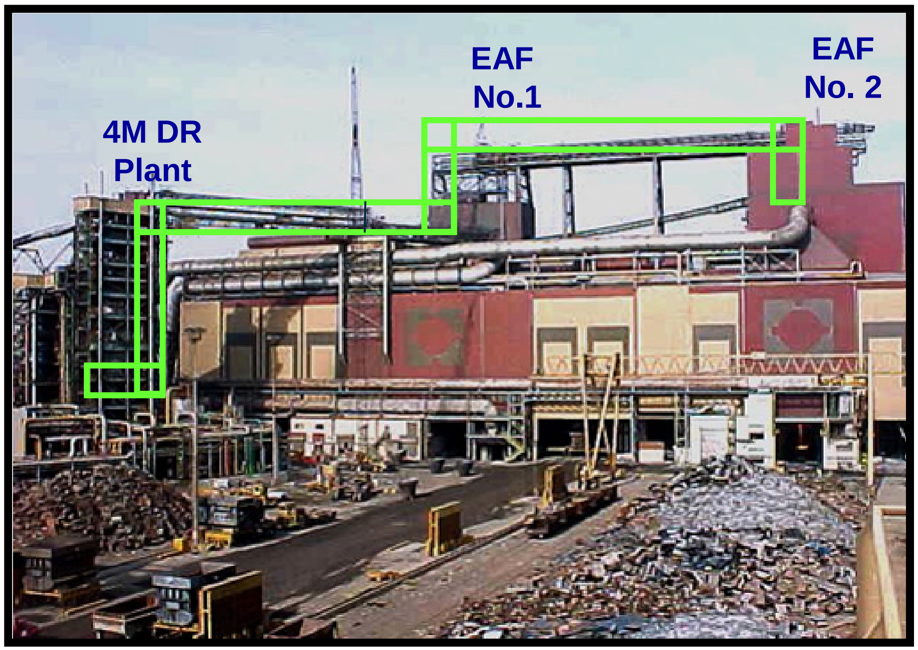
HYTEMP® System: Industrial Installation

- Ternium Monterrey is currently feeding two EAF's with Hot DRI.
- The Danieli EAF is fed with up to 100% High-Carbon, Hot DRI



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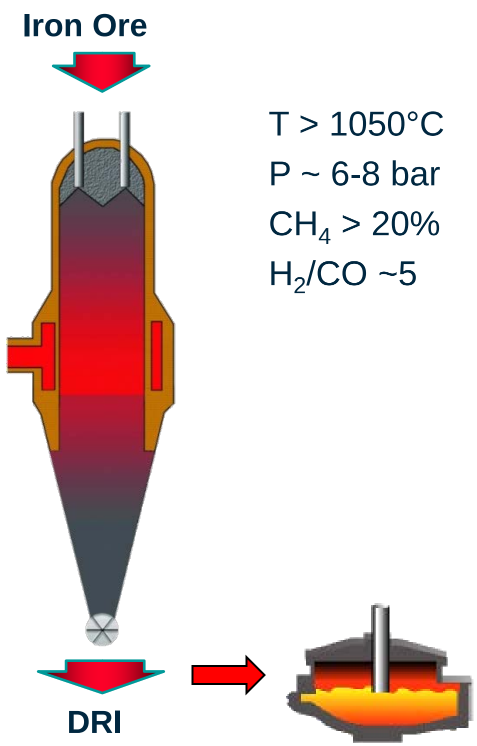
High-Carbon DRI

ENERGIRON DR Technology

High-Carbon DRI production



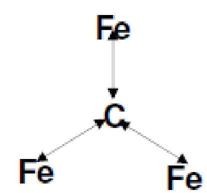
T > 1050°C
P ~ 6-8 bar
CH_4 > 20%
H_2/CO ~5

- Due to prevailing conditions of:
  - Temperature
  - Gas composition

  the ENERGIRON-ZR Process favors the diffusion of Carbon in the Iron matrix and the precipitation of Iron Carbide (Fe_3C).

Carburization

$$3Fe° + CH_4 \longrightarrow Fe_3C + 2H_2$$



- The DRI with a high content of Iron Carbide exhibits a much lower reactivity (no gas generated in any test conducted) than the standard DRI.

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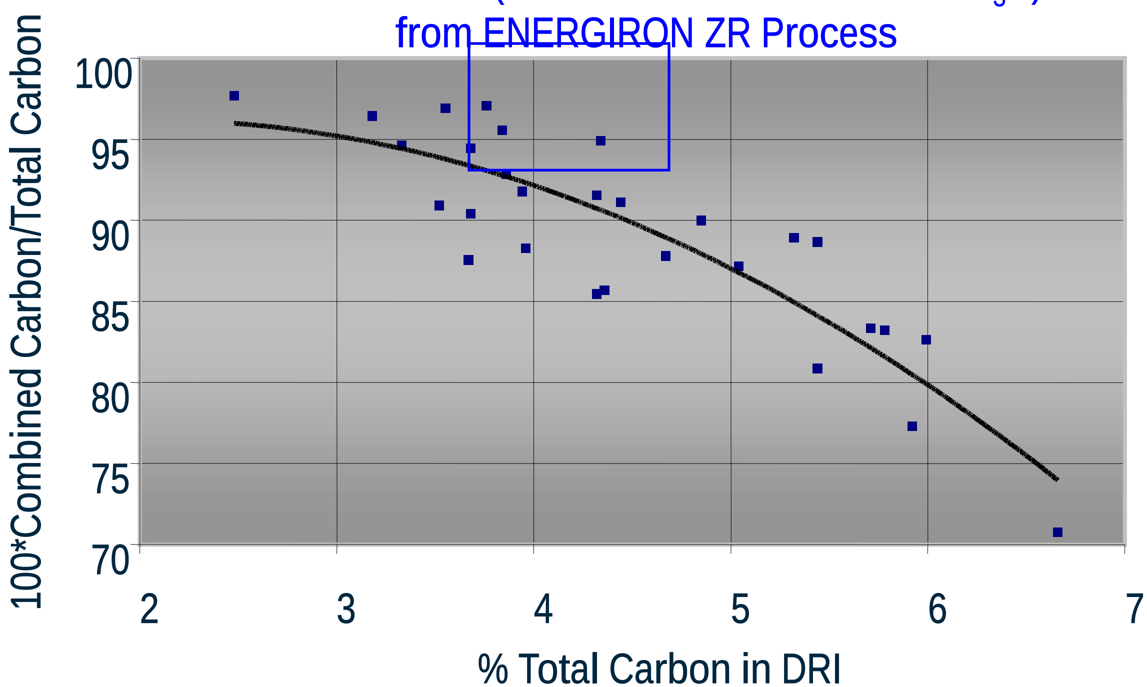
Effect of High-Carbon

% Combined Carbon (cementite or iron carbide - Fe_3C) in DRI from ENERGIRON ZR Process



DRI Analysis – 4M Plant:

Metallisation	94%
Carbon	4%
Fe°	83.0%
Fe Total	88.3%
Fe_3C	55.1%
Gangue	6.2%

- ✓ A DRI with 4% Carbon contains more than 50% of Fe_3C.
- ✓ The high percentage of Fe_3C in the DRI of the 4M plant makes the product very stable.
- ✓ Most of the Carbon in the DRI is present as Fe_3C, for a Carbon content of 4% approx. 95% of it is present as Fe_3C.
- ✓ Every 1% of combined Carbon corresponds to 13.5% of Fe_3C.

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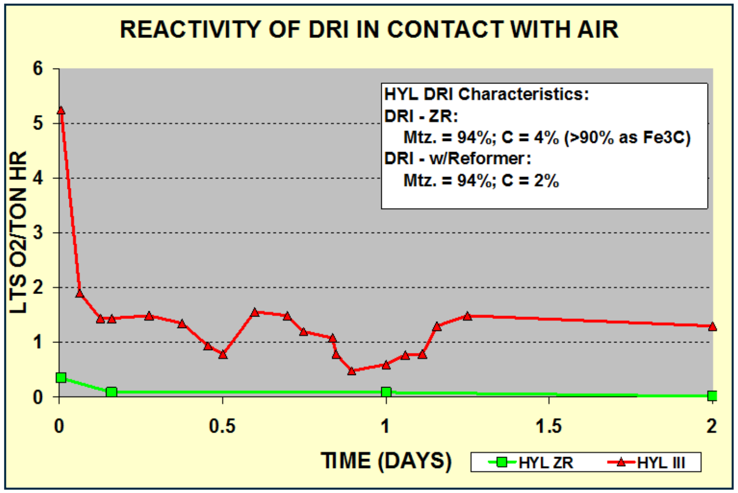
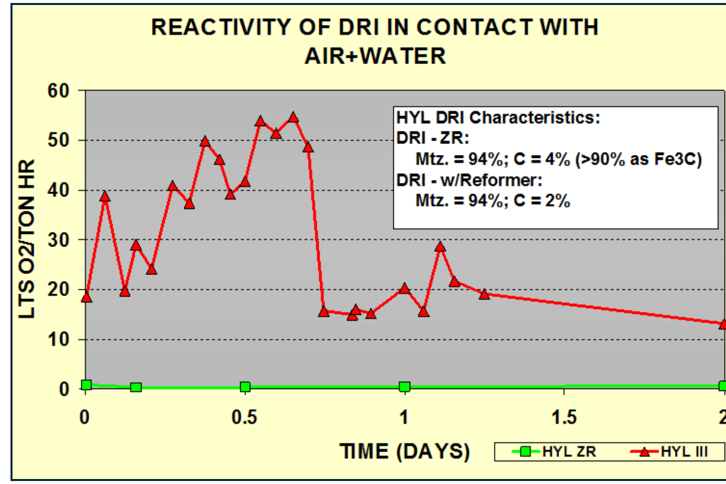
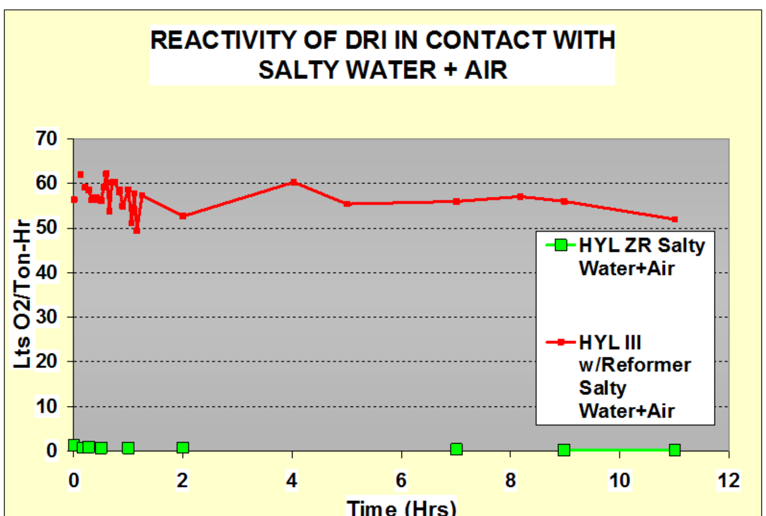
Stability of High Carbon DRI







- The High-C DRI from ENERGIRON ZR scheme, exhibits a much lower reactivity than the standard DRI.
- The onset temperature for the High Carbon DRI is much higher (>206°C) than for standard DRI (140°C)
- The tendency to re-oxidize is much lower for the High Carbon DRI (ODR ~ negligible) than that for a Standard DRI (ODR ~ 200 lts/t/d).

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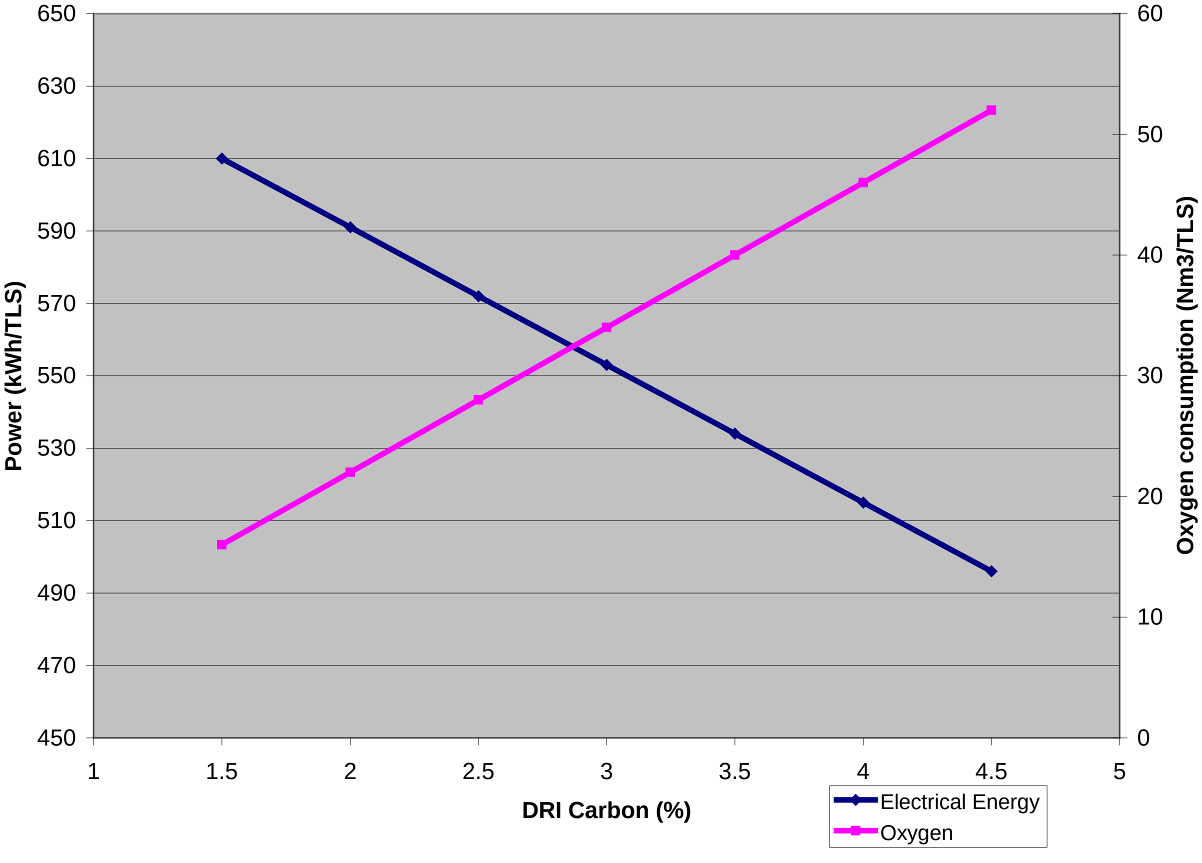
High Carbon DRI to EAF



- Most of Carbon in DRI from ENERGIRON DR process is Fe_3C.
- The Carbon in DRI is source of energy by the following main reactions:

  $2C + O_2$ ------> CO + Heat

  Fe_3C ---> 3Fe + C + Heat
- This provides ~ 33 kWh/tls per each 1% Carbon in the DRI.
- Necessary to use Oxygen; around 10 Nm^3 of O_2 / each 1% additional Carbon.

- *The benefits of high-carbon hot DRI have been demonstrated in the Ternium Monterrey meltshop while feeding up to 100% of hot DRI with about 94% metallization and close to 4% Carbon.*

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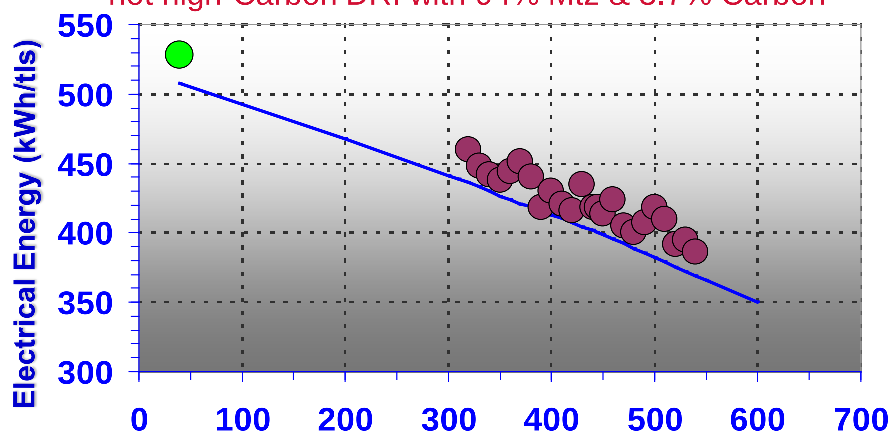
High Carbon - hot DRI to EAF

HYTEMP System ESI DRP UAE

- As compared to scrap, melting DRI in EAF demands more power because of DRI gangue content. However; the difference almost become null when comparing melting 100% scrap vs 100% high-Carbon, Hot DRI in the EAF.
  - ➢ For both cases, the power consumption ranges from 360 - 400 kWh/tls.



- The combination of high-Carbon at high temperature DRI yields power decrease of >160 kWh/tls and productivity increase of up to 22% for a practice of 90% hot-10% cold DRI (as compared to cold, low-C DRI).

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Direct reduction and Steel Making Integration Performance

ESI 1 case

	COLD DRI (1)	HOT DRI (2)
Temperature (°C)	30	600
Production (tph)	148	196
El. energy cons. (kWh/t l.s.)	550	<400
Oxygen cons. (Nm^3/t l.s.)	38	38
Electrode cons. (Kg/t l.s.)	1.6	1.4
Tap-to-tap (min)	61	<46

(1) 95% cold DRI + 5% scrap
(2) 90% hot DRI + 10% cold DRI

+ 32 % PRODUCTIVITY AT THE EAF WITH HOT DRI

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Conclusions

- Flexible DRP
  - already prepared for other Energy source
  - Iron ore quality; size and sulfur
  - Natural gas quality; heavy hydrocarbons and sulfur
- High DRI quality;
  - independent control for Metallization and Carbon
  - Higher Carbon content (~ 4%C)
- Selective CO_2 absorption for potential commercialization
- "HYTEMP" Safe, proven and reliable Hot DRI transport to EAF
- Intrinsically environmental friendly
- OPEX savings of approx. 12 – 19 MM US$/y
- Low construction costs of civil & erection works

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