Flexibility of the ENERGIRON Technology in DR Plants

3rd India International DRI Summit 2016
Is the innovative HYL Direct Reduction Technology developed jointly by Tenova and Danieli.

The most competitive and environmentally clean solution for lowering the liquid steel production cost.
Flexibility of the ENERGIRON Technology in DR Plants

OUTLINE

• ENERGIRON TECHNOLOGY
• PROCESS SCHEME
• PRODUCT CHARACTERISTICS
• REACTOR DESIGN
• ENVIRONMENTAL ASPECT
• LATEST ACHIEVEMENTS
• FUTURE
• TENOVA METALS
ENERGIRON
TECHNOLOGY
TECHNOLOGY: ENERGIRON ZR

FLEXIBILITY:
- Same scheme for ANY energy source

ENVIRONMENTAL:
- Low NOx emissions: 0.030 kg$_{NOx}$/t$_{DRI}$
- Selective removal of iron ore reduction’s by-products: H$_2$O & CO$_2$
FLEXIBILITY:
- Same scheme for ANY energy source

ENVIRONMENTAL:
- lowest NOx emissions: 0.030 kg\textsubscript{NOX} / t\textsubscript{DRI}
- Selective removal of iron ore reduction's by-products: H\textsubscript{2}O & CO\textsubscript{2}

- No concern for having heavy hydrocarbons in the NG
- Minimized electrical energy consumption

• High Temp: > 1050°C
• Operating pressure: 6-8 bar
Metallization > 94%
C in DRI 1.5 ÷ 4.5%
Up to 95% of C in Fe₃C form

YIELD < 1,38 t_{IO}/t_{DRI}
Thanks to high operating pressure

DRI is extracted from the Reactor to be stored at ambient temperature

DRI hot briquetted (650°C) to high density (5 g/cm³) pillow shaped briquettes

DRI is transferred from Reactor outlet to EAF at high temperature
## Energiron III vs Energiron ZR

<table>
<thead>
<tr>
<th>Energiron III</th>
<th>Energiron ZR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam reformer external to reduction circuit</td>
<td>Self-reforming reactions within the reactor</td>
</tr>
<tr>
<td>Reforming catalyst is Nickel-based</td>
<td>Reforming catalyst is DRI itself</td>
</tr>
<tr>
<td>No concerns for S &amp; heavy H-C in NG make-up</td>
<td>Make-up gas: NG, Syngas, BFG, COG</td>
</tr>
<tr>
<td>No concern for heavy H-C in NG: reforming with steam excess</td>
<td>Cracking of heavy H-C in NG takes place in reactor’s cone producing Cold DRI</td>
</tr>
<tr>
<td>Lowest electrical energy consumption</td>
<td>Lowest natural gas consumption</td>
</tr>
<tr>
<td>1.5 - 3.2% C in DRI, up to 60% as iron carbide</td>
<td>1.5 – 4.5% C in DRI, up to 95% as iron carbide</td>
</tr>
<tr>
<td>Unit</td>
<td>Energiron III</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Guaranteed Capacity</td>
<td>200,000 – 2,500,000</td>
</tr>
<tr>
<td>Yield (IO/DRI)</td>
<td>&lt; 1.38</td>
</tr>
<tr>
<td>Metallization</td>
<td>&gt; 94</td>
</tr>
<tr>
<td>NG Consumption</td>
<td>&lt; 2.6</td>
</tr>
<tr>
<td>El. Energy Consumption</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Oxygen Consumption</td>
<td>0.0 – 7.0</td>
</tr>
<tr>
<td>NO\textsubscript{X} Emissions (^{(1)})</td>
<td>0.030</td>
</tr>
<tr>
<td>CO\textsubscript{2} Emissions (^{(2)})</td>
<td>256</td>
</tr>
</tbody>
</table>

Notes:

1. BAT
2. With Selective Removal & Export
PRODUCT CHARACTERISTICS
HIGH-CARBON DRI: a unique product from ENERGIRON-ZR

Process conditions favors the Iron carbide formation

**HIGH-CARBON DRI:**
DRI with ≥3.5% C, with >90% as Fe₃C

**High-C DRI Analysis – Nucor DRP:**
- Metallization: 96%
- Carbon: 4.3%
- Fe*: 87.3%
- Fe Total: 90.9%
- Fe₃C: 58.5%
- Gangue: 3.8%

Iron Ore

T > 1050°C
P ~ 6-8 bar
CH₄ > 20%
H₂/CO ~5

In-situ Reforming
Reduction / Carburization

**Carburization**
3Fe° + CH₄ → Fe₃C + 2H₂

DRI with ≥3.5% C, with >90% as Fe₃C
HIGH-CARBON DRI from ENERGIRON-ZR: Stability

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

High-C DRI Analysis – Nucor DRP:
- Metallisation 96%
- Carbon 4.3%
- Fe° 87.3%
- Fe Total 90.9%
- Fe₃C 58.5%
- Gangue 3.8%

“Conventional” DRI analysis:
- Metallisation 94%
- Carbon 2.2%
- Fe° 89.2%
- Fe Total 92.9%
- Fe₃C 29.6%
- Gangue 3.9%
Packing chemical energy: CARBON in DRI

Carbon in EAF is required to reduce residual FeO in the DRI

**TRADITIONAL DRI**
- C ≈ 1.5 ± 2%
- ~ 20% C in GRAPHITE form
- YIELD
  - Injected carbon ≈ 40%
  - Particles blow off
  - Ash/impurities

**ENERGIRON DRI**
- C ≈ 1.5 - 4%
- C mostly in CEMENTITE form
- YIELD
  - Carbon bond to DRI ≈ 100%
  - ~ 36 kWh / t
  - ~ 10 Nm\(^3\) O\(_2\) / 1% C

**CARBURIZATION IN ENERGIRON PROCESS**

\[
3Fe^0 + CH_4 \rightarrow Fe_3C + 2H_2
\]

\[T > 1050 °C\]
\[P ≈ 6 ÷ 8 \text{ barg}\]
\[CH_4 > 20\%\]
\[H_2 / CO ≈ 5\]

**CEMENTITE IS SOURCE OF ENERGY IN EAF**

\[
Fe_3C \rightarrow 3Fe + C + \text{Heat}
\]
\[
2C + O_2 \rightarrow CO + \text{Heat}
\]

- For Fe\(_3\)C dissociation heat is:
  - ~ 8 kWh/t\(_{DRI}\) for each 1% Carbon
- Total: ~ 36 - 40 kWh/t\(_{DRI}\) per each 1% Carbon in the DRI
ENVIRONMENT-FRIENDLY DR TECHNOLOGY
The steelmaking industry is characterized by intensive use of fossil fuels, which leads to a significant impact to the environment through Global Warming-Greenhouse Gases (GHG), mainly in the form of CO$_2$ Emissions.

**Primary energy source for reduction of iron oxides**

<table>
<thead>
<tr>
<th>Integrated Steelmaking Mill</th>
<th>DR-EAF route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coking Coal</td>
<td>Natural Gas</td>
</tr>
</tbody>
</table>

But also:
- **Syngas** (coal gasification)
- **Coke Oven Gas** (COG)

In general, just based on the use of coal in the BF-BOF route as compared with NG in case of the DR-EAF route, the DR-EAF route emits **40%-60% less CO$_2$ per ton of liquid steel**, depending on the plant location.
Selective CO$_2$ Removal

**ENERGIRON ZR SCHEME**

**FLEXIBILITY:**
- Same scheme for ANY energy source

**ENVIRONMENTAL:**
- Lowest NOx emissions: 0.030 kg NOx/tDRI
- Selective removal of iron ore reduction’s by-products: H$_2$O & CO$_2$:
  - CO$_2$ as by-product

From Total Carbon input:
- About 60% as SELECTIVE CO$_2$
  - can be sequestrated and/or sold as by-product

**DRI QUALITY:**
- > 94% Mtz; 2%-4.5% Carbon (as Fe$_3$C)
COMMERCIALIZATION OF CO$_2$ IN HYL/ENERGIRON DR PLANTS

Since 1998, CO$_2$ gas, from the CO$_2$ absorption system of HYL/ENERGIRON plants, has been used as byproduct by different off-takers:

<table>
<thead>
<tr>
<th>HYL/ENERGIRON DR Plant</th>
<th>Off-taking Company</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ternium; Monterrey, Mexico</td>
<td>Praxair</td>
<td>Food and beverages industries</td>
</tr>
<tr>
<td>Ternium; Puebla, Mexico</td>
<td>Infra</td>
<td>Beverages industries</td>
</tr>
<tr>
<td>PTKS; Indonesia</td>
<td>Janator</td>
<td>Food industry</td>
</tr>
<tr>
<td>PSSB; Malaysia</td>
<td>Air Liquid/MOQ</td>
<td>Food industry</td>
</tr>
<tr>
<td>JSW Salav; India</td>
<td>Air Liquid</td>
<td>Dry ice</td>
</tr>
<tr>
<td>Emirates Steel; UAE (1)</td>
<td>Masdar/ADNOC</td>
<td>Enhanced Oil Recovery (EOR)</td>
</tr>
<tr>
<td>Nucor; USA (2)</td>
<td>Denbury Resources Inc.</td>
<td>Nearby piping network; EOR</td>
</tr>
</tbody>
</table>

Note (1): On-going project.
Note (2): To be executed. Additionally NUCOR has a SULFEROX system that removes sulfur from the CO$_2$ stream.
**Emissions Compliance Example:**
As an example of specific compliance with strict environmental regulations, actual data are indicated in the table below for *Minnesota EPA granted permit*. It can be noted that no particular methods, and/or additional equipment, is necessary to fulfill the local regulations:

<table>
<thead>
<tr>
<th>Gaseous Pollutants</th>
<th>Minnesota Environmental regulation</th>
<th>Achieved value in ENERGIRON plant</th>
<th>Specific Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate</td>
<td>0.014 grains/dscf</td>
<td>0.01 grains/dscf</td>
<td>None</td>
</tr>
<tr>
<td>SO₂</td>
<td>15 lb/hr, 24-hour average.</td>
<td>14.1 lb/hr</td>
<td>None</td>
</tr>
<tr>
<td>NOₓ</td>
<td>96 ppmv @ 3% O₂ 152 lb/hr, 24-hour average</td>
<td>85 ppmv (max) – 25 ppmv (min) 75 lb/hr</td>
<td>Just use of low NOₓ burners.</td>
</tr>
<tr>
<td>CO</td>
<td>32 lb/hr, 24-hour average.</td>
<td>16.6 lb/hr</td>
<td>None</td>
</tr>
<tr>
<td>VOC</td>
<td>2 lb/hr, 24-hour average</td>
<td>0</td>
<td>None</td>
</tr>
</tbody>
</table>

ENERGIRON TECHNOLOGY HAS BEEN ALREADY PERMITTED TWICE IN THE U.S.
REACTOR SIZES
## ENERGIRON DR PLANTS: Standard Modules

<table>
<thead>
<tr>
<th>Capacity (Mt/year)</th>
<th>Reactor size (ID- m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200,000</td>
<td>(Micro-Module) 2.5</td>
</tr>
<tr>
<td>500,000</td>
<td>4.0</td>
</tr>
<tr>
<td>800,000</td>
<td>4.5</td>
</tr>
<tr>
<td>1,200,000</td>
<td>5.0</td>
</tr>
<tr>
<td>1,600,000</td>
<td>5.7</td>
</tr>
<tr>
<td>2,000,000</td>
<td>6.0</td>
</tr>
<tr>
<td>2,500,000</td>
<td>6.5</td>
</tr>
</tbody>
</table>
ENERGIRON: ONE BIG STEP FORWARD

UNMATCHED EXPERIENCE FROM THE SMALLEST TO THE LARGEST DR MODULES WORLDWIDE

One module

0.20 MTPY
Carbon 3.0% - 4%
Metallization 94%
Cold DRI

Start up 2010

One module

1.6 → 2.0 MTPY
Carbon 2.0 % - 2.5%
Metallization 94%
Hot/Cold DRI

Start up 2009/2011

One module

2.0 MTPY
Carbon 3.0% - 4.0%
Metallization 94% - 96%
Hot/Cold DRI

Start up 2013

One module

2.5 MTPY
Carbon 3.6% - 4.0%
Metallization 95% - 96.5%
Cold DRI

Start up 2013
EZZ ROLLING MILL STEEL
EGYPT
TECHNOLOGY: ENERGIRON III
NOMINAL CAPACITY: 2.0 Mtpy COLD DRI
LOCATION: Ain Suhkna, Egypt

✓ DANIELI turn-key project
✓ External reformer
✓ Cold discharge reactor
✓ Fed by NG
✓ Captive production
THE 2.0 MTPY DR PLANT AT AL-EZZ IS THE MOST RECENT ENERGIRON PLANT TO BE STARTED-UP

HOT COMMISSIONING TIMETABLE

FIRST DRI PRODUCTION 22nd Nov. 2015
HOT TEST COMPLETION (3 days) 2nd Dec. 2015
NG AVAILABILITY RESTORED 14th Dec. 2015
FULL PRODUCTION RESUMED 15th Dec. 2015
PERFORMANCE TEST COMPLETION (5 days) 20th Dec. 2015

FIRST DRI 22nd Nov

CONTINUOUS OPERATION

29 days

PT COMPLETION 20th Dec
Guaranteed capacity: 237.5 t/h

Natural Gas available at nominal rate

112% Actual production with NG available at nominal rate

Hourly production [t/h]

Maximum expected production due to NG / utilities availability [t/h]
### CONSUMPTION FIGURES ACHIEVED DURING PERFORMANCE TEST

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield*</td>
<td>t_{Oxide} / t_{DRI}</td>
<td>1.37</td>
</tr>
<tr>
<td>Metallization</td>
<td>%</td>
<td>&gt;94</td>
</tr>
<tr>
<td>Carbon content</td>
<td>%</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Gcal/t_{DRI}</td>
<td>2.57</td>
</tr>
<tr>
<td>Electric Energy</td>
<td>kWh/t_{DRI}</td>
<td>30</td>
</tr>
</tbody>
</table>

* Screened at 3.2 mm
## Project List

<table>
<thead>
<tr>
<th>Project</th>
<th>Contract date</th>
<th>Capacity (Mtpy)</th>
<th>Danieli/HYL</th>
<th>HYL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micromodule Abu Dhabi (ESI-3)</td>
<td>2005</td>
<td>0.200</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>ESI-1 (Abu Dhabi)</td>
<td>2006</td>
<td>1.600 → 2.000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sidor (Venezuela)</td>
<td>2006</td>
<td>0.800</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Suez Steel (Egypt)</td>
<td>2007</td>
<td>2.000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ESI-2 (Abu Dhabi)</td>
<td>2008</td>
<td>1.600 → 2.000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Al Ezz (Egypt)</td>
<td>2009</td>
<td>2.000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TiTB (SEA)</td>
<td>2010</td>
<td>0.500</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Nucor (USA)</td>
<td>2010</td>
<td>2.500</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>JSPL-2 Angul (India) –currently on hold</td>
<td>2011</td>
<td>2.500</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
TENOVA
THANK YOU