THE INNOVATIVE DIRECT REDUCTION TECHNOLOGY

Joel Morales
MARKETING MANAGER/TENOVA HYL
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INNOVATION IN DR TECHNOLOGY
FIRST & PIONEER, over 50 yrs of Innovation

- Pioneering in direct reduction since the 1950s with the WORLD’S FIRST INDUSTRIAL PLANT at Monterrey, Mexico in 1957. (Recognized as Historical Landmark by American Society for Metals)

- In the 1980s Tenova HYL initiated the pressurized process, to optimize investment and to take advantage of the normally high NG available pressure.

- FIRST HYL pilot plant operation in 1984 without external reformer:
  State-of-the-art ZR scheme, most advanced, simplest, efficient for producing high quality DRI,

- In the 1990s, Tenova HYL eliminated the need for the natural gas/steam reformer, implementing «in-situ» reforming or ZR process.

- FIRST industrial plant operation, Hylsa 4M plant, Monterrey, with ZR scheme, production of C/H High-Carbon DRI (3.0%-4.5%) and HYTEMP® System for hot DRI charging to EAF in 1998:
  Hot & Cold High-Carbon DRI
FIRST & PIONEER, over 50 yrs of Innovation

- FIRST HYL Micromodule plant of 0.2 Mtpy built, GSPI, Abu Dhabi in 2006.

- Since 2006, Tenova HYL and Danieli & C joined efforts to commercialize the technology under the brand name ENERGIRON.
  - ENERGIRON is the innovative HYL Direct Reduction Technology developed jointly by Tenova and Danieli -

- FIRST new generation ENERGIRON ZR plant of 2.0 Mtpy for Suez Steel in 2009.

- FIRST world largest ENERGIRON ZR plant in a single module of 2.5 Mtpy for Nucor Steel in 2010.
Commercially, since 2006 Tenova HYL has joined with Danieli to form the ENERGIRON alliance

- Energiron is the Innovative HYL Direct Reduction Technology jointly developed by Tenova and Danieli.
- Our combined resources are supplying the world’s most advanced DR plants to steelmakers worldwide.
SELECTING THE RIGHT TECHNOLOGY
Introduction

• ENERGIRON DR technology is the state-of-the-art in direct reduction. It uses a simple plant configuration, has flexibility for using different sources of reducing gases and has the most efficient and flexible use of iron ores.

• Not only can natural gas be used, but also Coke Oven Gas and Syngas, in the same reliable and simple configuration.

• The process uniquely has the ability to produce High Carbon DRI, with important benefits in terms of higher stability, steel production costs and productivity.

• A key factor in many of the process advantages is directly related to the pressurized operation.
DRI QUALITY:
> 94% Mtz; 2%-4.5% Carbon (as Fe$_3$C)

OPEX:
✓ Highest overall Energy efficiency
  ▪ Overall optimization: ~ 2.4 GJ/t;

- High operating pressure:
  - < 80 kWh/t
  - High yield: <1.4 t IO/t (1)

(1) The higher the operating pressure ⇒ the lower the gas velocity ⇒ the lower the dragging force ⇒ the LESS dust carry-over ⇒ the LOWER iron ore consumption
ENERGIRON ZR PROCESS: PRESSURIZED OPERATION

- Operating Pressure: typically 6-8 bar A
- Impact on:
  - Higher plant capacity/size ratio
    - Smaller equipment size
  - Lower iron ore consumption
    - Lower gas velocities/dragging force / less fines carry over
  - Lower power consumption
    - Lower compression factor
  - Better use of iron ore fines
    - Higher fines input (+3.2mm)

- These factors are reflected in both, investment and operating costs

Gas velocity with pressure at top gas

Other DR technology: ENERGIRON Technology:

\[
V_g @ 1 \text{ barA} = 5 \text{ m/s} \quad V_g @ 8 \text{ barA} = 2 \text{ m/s}
\]

\[
\text{Compression} \propto (\frac{P_2}{P_1})^k
\]

\[
P_{in} = 8 \text{ barA}
\]

\[
P_{out} = 11.4 \text{ barA}
\]

\[
P = 8.4 \text{ barA}
\]

\[
\begin{array}{|c|c|}
\hline
\text{Suction Pressure} & 8.0 \text{ Bar a} \\
\text{Discharge Pressure} & 11.4 \text{ Bar a} \\
\text{Gas Flow} & 100000 \text{ Nm}^3/\text{h} \\
\text{Power} & 1240.0 \text{ kW} \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|}
\hline
\text{Suction Pressure} & 1.5 \text{ Bar a} \\
\text{Discharge pressure} & 4.9 \text{ Bar a} \\
\text{Gas Flow} & 100000 \text{ Nm}^3/\text{h} \\
\text{Power} & 4670.0 \text{ kW} \\
\hline
\end{array}
\]
**ENERGIRON ZR PROCESS: FLEXIBILITY**

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

**ENVIRONMENTAL:**
✓ lowest NOx emissions
✓ CO₂ as by-product

From Total Carbon input:

62% as SELECTIVE CO₂
Approx. 256 kgCO₂ / tDRI
can be sequestered and/or sold as by-product
HIGH-CARBON DRI: a unique product from ENERGIRON-ZR

Iron Ore

In-situ Reforming
CH₄ + H₂O → CO + 3H₂
CH₄ + CO₂ → 2CO + 2H₂

Reduction
Fe₂O₃ + 3CO → 2Fe° + 3CO₂
Fe₂O₃ + 3H₂ → 2Fe° + 3H₂O

Carburization
3Fe° + CH₄ → Fe₃C + 2H₂

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

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

HIGH-CARBON DRI Analysis – Nucor DRP:
Metallization 96%
Carbon 4.3%
Fe° 87.3%
Fe Total 90.9%
Fe₃C 58.5%
Gangue 3.8%

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, as proven by a number of tests and actual DRI behavior in operating plants.
HIGH-CARBON DRI: a unique product from ENERGIRON-ZR

\[
\begin{align*}
\text{Fe}_3\text{C}(l) & \rightarrow 3\text{Fe}(l) + \text{C}(s) \quad \Delta G_{1673^\circ C} = -522.7 \text{ kJ mol}^{-1} \text{Fe} \\
2\text{C}(s) + \text{O}_2(g) & \rightarrow 2\text{CO}(g) \quad \Delta G_{1673^\circ C} \approx -530.0 \text{ kJ mol}^{-1} \text{O}_2
\end{align*}
\]

Depending on post-combustion factor

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Water type</th>
<th>Temperature (°C)</th>
<th>Maximum rate of gas generation (l/hr/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>distilled</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>distilled</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>distilled</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>sea</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>sea</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>sea</td>
<td>ambient</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>distilled</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>distilled</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>distilled</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>sea</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
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<td>40</td>
<td>0</td>
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<tr>
<td>12</td>
<td>sea</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>distilled</td>
<td>80</td>
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</tr>
<tr>
<td>14</td>
<td>distilled</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>distilled</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>sea</td>
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<td>0</td>
</tr>
<tr>
<td>17</td>
<td>sea</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>sea</td>
<td>80</td>
<td>0</td>
</tr>
</tbody>
</table>

Test Report - Substances that in contact with water emit flammable gases.

Stability

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, as proven by a number of tests and actual DRI behavior in operating plants.

For Fe₃C dissociation heat (Note 1) is ~ 8 kWh/t_DRI for each 1% Carbon

Total (Note 2): ~ 36 - 40 kWh/t_DRI per each 1% Carbon in the DRI

(Note 1)
\[
\text{Fe}_3\text{C}(l) \rightarrow 3\text{Fe}(l) + \text{C}(s)
\]

(Note 2)
Depending on post-combustion factor
High-Carbon DRI provides very important benefits to the EAF:

- It contains additional energy as compared to the standard DRI, reducing the electrical power consumption and increasing the EAF productivity.
- Reducing or eliminating the need of carbon injection to EAF

Additionally, among many others:
- Creating and maintaining foamy slag throughout the melting process
- Oxygen injection matching Carbon input (from DRI) and controlled as per DRI feeding rate

For users of High-C DRI, there’s no going back (i.e. Ternium, Nucor, Suez, ESI). Are they all wrong?
ENERGIRON DR Technology: HYTEMP System

- First industrial installation in 1998
- Pneumatic transport of Hot DRI to EAF’s in a totally enclosed system - No gases or material losses. No effect on DRI quality
- Performances - More than 23 million tons of Hot DRI already transported
- Reliability - Time availability record of 100%

- Fully automated and integrated system
- No wearing parts and almost maintenance-free
- Minimum heat losses:
  HDRI at EAF: T > 600°C; with ANY % Carbon in DRI
- Compliance with all safety regulations
THE REFERENCES
FROM THE SMALLEST TO THE LARGEST
<table>
<thead>
<tr>
<th>Company</th>
<th>Module Type</th>
<th>Capacity (MTPY)</th>
<th>Carbon (%)</th>
<th>Metallization (%)</th>
<th>DRI Type</th>
<th>Start up</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESI3 Micromodule</td>
<td>One module</td>
<td>0.20</td>
<td>3.0% - 4%</td>
<td>94%</td>
<td>Cold DRI</td>
<td>2010</td>
</tr>
<tr>
<td>ESI 1 &amp; 2</td>
<td>One module</td>
<td>1.6 - 2.0</td>
<td>2.0% - 2.5%</td>
<td>94%</td>
<td>Hot/Cold DRI</td>
<td>2009/2011</td>
</tr>
<tr>
<td>Suez Steel</td>
<td>One module</td>
<td>2.0</td>
<td>3.0% - 4%</td>
<td>94% - 96%</td>
<td>Hot/Cold DRI</td>
<td>2013</td>
</tr>
<tr>
<td>Nucor</td>
<td>One module</td>
<td>2.5</td>
<td>3.0% - 4.5%</td>
<td>95% - 96.5%</td>
<td>Cold DRI</td>
<td>2013</td>
</tr>
</tbody>
</table>

UNMATCHED EXPERIENCE FROM THE SMALLEST TO THE LARGEST DR MODULES WORLDWIDE
First Micromodule

- 200,000 metric t/y
- ZR plant for high carbon DRI
- Started up 2010
- 94% Mtz; 3.6% Carbon

- Small footprint
- Low CAPEX (lower financial commitment)
- Onsite DRI production and substituting high price low residual scrap and pig iron, reducing steel production cost.
EMIRATES STEEL: Performance Test results

<table>
<thead>
<tr>
<th>DRP ENERGIRON PARAMETER</th>
<th>UNIT</th>
<th>ACHIEVED RESULT</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>tonne</td>
<td>78579</td>
<td>75000</td>
</tr>
<tr>
<td>Metallization (avg)</td>
<td>%</td>
<td>95.28</td>
<td>94</td>
</tr>
<tr>
<td>Carbon Content (avg)</td>
<td>%</td>
<td>2.56</td>
<td>2.5</td>
</tr>
<tr>
<td>Natural Gas Consumption (avg)</td>
<td>Net Gcal/tDRI</td>
<td>2.52</td>
<td>2.65</td>
</tr>
<tr>
<td>Electricity consumption (only DRP Core)</td>
<td>kWh/tDRI</td>
<td>24.14</td>
<td>35</td>
</tr>
<tr>
<td>Cold DRI Temperature (avg)</td>
<td>°C</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>Iron Oxide consumption</td>
<td>t IOP/t of DRI</td>
<td>1.41</td>
<td>1.44</td>
</tr>
</tbody>
</table>

**Test results after revamp of ESI II:** from 1.6Mtpy to 2.0Mtpy

**EAF Performance**

| Electric consumption | 380 kWh/tLs | 520 kWh/tLs |
| Tap - Tap Time       | 38 min      | 52 min      |

**Condition 1**
- 90% Hot DRI
- 10% Cold DRI
- Mtz. 95.7%
- C 2%

**Condition 2**
- 0% Hot DRI
- 100% Cold DRI
- Mtz. 96%
- C 2%
REFERENCES: SUEZ STEEL, EGYPT

SUEZ STEEL
**SUEZ STEEL: Performance Test results**

<table>
<thead>
<tr>
<th>DRP ENERGIRON ZR PARAMETER</th>
<th>UNIT</th>
<th>ACHIEVED RESULT</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>tonne</td>
<td>29,262</td>
<td>29,250</td>
</tr>
<tr>
<td>Metallisation (avg)</td>
<td>%</td>
<td>94.28</td>
<td>94</td>
</tr>
<tr>
<td>Carbon content (avg)</td>
<td>%</td>
<td>3.52</td>
<td>3.5</td>
</tr>
<tr>
<td>Natural gas consumption (avg)</td>
<td>Net Gcal/t&lt;sub&gt;DRI&lt;/sub&gt;</td>
<td>2.40</td>
<td>2.42</td>
</tr>
<tr>
<td>Electricity consumption (incl: DRP Core + MH + Aux systems+ CAP)</td>
<td>kWh/t&lt;sub&gt;DRI&lt;/sub&gt;</td>
<td>93.17</td>
<td>95</td>
</tr>
<tr>
<td>Hot DRI Temperature</td>
<td>°C</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Iron oxide Consumption (dry, screened)</td>
<td>t&lt;sub&gt;IO&lt;/sub&gt; / t&lt;sub&gt;DRI&lt;/sub&gt;</td>
<td>1.38</td>
<td>1.40</td>
</tr>
</tbody>
</table>
NUCOR STEEL

2,500,000 t/y - NUCOR St. James Parish, Louisiana (ENERGIRON)

- World’s largest single DR module of 2.5 MTPY for Cold DRI Production
- The only US plant in operation
- Started up 24\textsuperscript{th} Dec 2013
- Reached 95% metallization and \( \geq 4\% \) carbon in the first 24 hours of operation
- Zero Reformer technology
NUCOR STEEL

Is the **ONLY** worldwide DR plant, since re-start up:

- Producing under stable and continuous operation > 300 t/h
- Producing DRI with Mtz ≥ 96%
- Producing DRI with Carbon ~ 4%
- Achieving all above simultaneously!

Additionally:

The LOWEST NG and power consumption, considering the above DRI quality and selective CO₂ removal: << 2.4 Gcal/t
LAST BUT NOT LEAST
The HYL/ENERGIRON DRP’s have demonstrated to perform at the same level or even better than competing DR-based technologies plants, achieving >90% capacity just in 1-2 yrs operation.
THANK YOU