In this issue

- Performance and reliability of Energiron plants
- Emirates Steel sets new record in DRI production
Alongside Innovation, Sustainability and Safety, one of the fundamental pillars that inspire Tenova’s daily operations is **Reliability**.

While we design, fabricate and operate our products, we strive to have them made to last and to produce what they were designed for. We are a team of professionals committed to provide dependable technology.

It is commonly heard in the DRI market that “Ironmaking isn’t about how many tons you make in an hour; it’s about how many hours you make tons”. We cannot but agree with this statement and facts confirm that our technology and our plants are already in this path.

This year that is about to end has in fact brought plenty of satisfactions to most of our licensees. These results have been accomplished with team spirit and constant and dedicated effort and attention to details. Our goal is to provide outstanding service attitude, delivering what we promised.

A few more challenges must be overcome yet and we are not sitting on our successes, but rather motivated by the willingness to continuously improve the results of all the Energiron plants. We have shown our commitment to providing zero latency in learning by a few possible mistakes that may result from incremental innovation.

I take the chance to wish a prosperous new year to all the readers of the HYL News, sure that 2018 will be an excellent year for all DRI producers and users.

**Stefano Maggiolino**
President & CEO
TENOVA HYL
In this issue of HYL News, we address the reliability of Energiron Plants. This reliability comes about as the result of extensive experience acquired and lessons learned through many years in the Direct Reduction business. As one of our four corporate pillars, plant reliability is a main target for any existing or new Energiron Plant.

It’s not always easy to show excellent results when the industry is in a down cycle. What is crucial, however, is that the plant be able to produce consistently and reliably when it is required to supply the needed DRI feed for the steelmaking operations. This is a key feature of the Energiron technology – with easy and efficient startup and turndown procedures and highly efficient use of iron ore and reducing gas that keep the OPEX lower than any other in the industry. When production runs are crucial, reduced operating costs mean the difference between profitability and losing money.

A clear example of this reliability and continuous results improvement is the new DRI production record achieved in 2016-2017 by Emirates Steel of Abu Dhabi, UAE, surpassing the nameplate capacity and operating well beyond its design. We let the facts speak for themselves.

We hope you find the articles in this issue to be informative and we welcome your comments and observations. You can always find additional information through our websites at www.tenova.com and www.energiron.com
PERFORMANCE AND RELIABILITY OF ENERGIRON PLANTS

INTRODUCTION

The direct reduction technology has significantly evolved over the last decades to keep up with the new requirements of the steel industry. The major challenges that the direct reduction sector had to face were mainly related to:

• the increase of production capacity, that until the early 2000s was a bottleneck towards the downstream steelmaking process;
• the OPEX reduction, a fundamental factor that allows greater competitiveness in times of downward pricing;
• the increase of the DRI quality, a fundamental step to optimize the EAF operations and therefore to increase the DRI appeal as a valuable feeding material;
• flexibility and ease of operation, allowing plant owners to consider a wider range of raw materials (i.e. more opportunities) while keeping the process in a steady state and fully under control.

Among all the available technologies, ENERGIRON characterized itself since its establishment by raising the bar and setting new limits to all these challenges imposed by the dynamicity of the steel sector.

In just one decade, ENERGIRON was successful in increasing the production capacity of a single Direct Reduction (DR) module from a maximum of 1.2 Million tons of DRI per year to the largest operating DR plant in the world, capable of producing 2.5 Mtpy of premium quality DRI. This upsizing is more difficult to achieve than one may think and it was possible thanks to continuous improvements; in fact, during the last 10 years ENERGIRON realized the first 1.6 Mtpy plant, than the capacity was progressively raised to 1.9 Mtpy, 2.0 Mtpy and finally to 2.5 Mtpy, that still today remains the record. Each one of these successful projects was a world’s first and a new challenge. Today ENERGIRON can provide a well proven DR module that fits all the steelmaking needs: standard modules are available with capacities from 0.25 Mtpy to 2.5 Mtpy.

The recent developments of the ENERGIRON technology go well beyond the increase of plant capacity. The ENERGIRON DRI product is recognized as a unique premium material, thanks to its high metallization and energy content. The basic process scheme remains unchanged for any gaseous reducing source (COG, BFG, NG, Reformed Gas) and it’s also ready to use Hydrogen, that in the future is envisaged to replace carbon for all the high energy intensive industries. Energy efficiency is a milestone on which this technology has been developed so, thanks to the careful design, the energy requirements of any ENERGIRON plant hit the lowest levels for this industry, and finally this results in the lowest OPEX.

To make all this possible, it is of fundamental importance to cover every single detail and make sure that the plant is always operating at its optimal working point. The ENERGIRON process is controlled by more than 5,500 analog and digital variables, which are automatically analyzed by the automation system. All the process variables coming from
ANALYSIS BASED ON ACTUAL OPERATING DATA
PRODUCTIVITY, EFFICIENCY AND PRODUCTION COSTS

the field instruments are constantly collected by the various acquisition systems (PLCs, HMIs), providing a valuable set of information for continuously monitoring and optimizing the process. The proprietary ENERGIRON advanced software takes advantage of this huge potential by managing integrated data collection, analysis, and web reporting with powerful statistical tools to support decision-making. This finally makes it possible to further optimize the process efficiency, by detecting the optimal set points in real-time, with consequent important energy savings.

MAXIMIZING THE PRODUCTION CAPACITY

As mentioned before, ENERGIRON is the pioneer in increasing DR plants production capacity, with the objective of satisfying all requirements from the downstream steelmaking process. Production data collected from various plants in operation and hereby summarized prove the following FACTS:

• The design and Installation of high capacity DR plants (>1.6 million tpy) started in 2006 with the establishment of the ENERGIRON alliance. Today ENERGIRON’s high capacity plants are a consolidated reality.

• DR plants based on technologies other than ENERGIRON and designed for high capacities are today still prototypes, either under construction or in start-up phase. To date, ENERGIRON is the only technology having proven references over a long term period for installations designed to produce more than 2.0 MTPY. As a matter of fact, ENERGIRON can count on a reference of five DR plants capable of exceeding 2.0 MTPY, namely: Emirates Steel n. 1 and 2, Suez Steel Co., Ezz Rolling Mills and Nucor Steel Louisiana.

UNMATCHED EXPERIENCE IN HIGH CAPACITY MODULES
The scaling up of ENERGIRON DR Plants from 1.6 to 2.5 million tpy was progressive and smooth. The higher pressure at which ENERGIRON plants operate is certainly the cornerstone for this success, resulting in smaller reactor diameter for the same plant capacity that finally results in better gas distribution and product quality.

Thanks to the experience gained in this last decade of implementation of high capacity plants, ENERGIRON has completely debugged the design, optimizing process and plant equipment in team-up with operators and vendors. As a result of such debugging, today the ENERGIRON high capacity plants can properly perform according to standard operational availability.

ENERGIRON plants have demonstrated and proved a better learning curve compared to any other DR technology. Other DR processes seem not to be suitable for high capacities, mainly due to lower pressure process concept or mechanical issues related to Rotary Kilns.

LEBEDINSKY GOK DRP (900,000 ton per year HBI, achieved 1,100,000 ton per year)

EMIRATES STEEL. ENERGIRON DRP 1 & 2 (cap: 2,000,000 ton per year HDRI/CDRI

The final proof of the ENERGIRON maturity is its superior learning curve compared to any other DR technology. The latest ENERGIRON high-capacity plant to be started-up is the Al-Ezz module in November 2015, having experienced a world record startup period: in only 29 days from the first produced DRI, the plant was already operating well above the design values and learning curve, achieving up to 112% of the guaranteed production value.
The performance gap towards any other technology is further reflected in the overall plant learning curve, which can grant to the Customer a 20% shorter payback period. Moreover, the ENERGIRON team project execution concept is to support the Client and its Contractors in all project activities from kick off meeting till end of performance test, as well as during post commissioning period. This approach allows fulfilling the contractual time schedule without delays.

LATEST GENERATION OF ENERGIRON PLANTS:
PROTOTYPE PHASE HAS CONCLUDED

As a result of the extensive experience acquired during recent projects, ENERGIRON plants incorporate all the features needed to provide maximum plant availability, reliability and performances. In particular, the Process Gas Heater (PGH) now incorporates only proven solutions already implemented in the oil & gas industry. The collaborative approach with reputable vendors has resulted in equipment design which takes into account all lessons learned from previous projects and improves the equipment reliability. In particular, the updated design of ZR Heaters features a system to maintain it at full efficiency by removing traces of deposited carbon without affecting the metallic structure of tubes. This system, normally used in SSC (Suez Steel), Nucor Steel and also in Ternium Plants, demonstrated to be effective and fast enough to allow full cleaning of ZR PGHs in less than 24 hours. Moreover, the automation system monitoring the PGH is able to detect in advance any possible malfunction (e.g. CO monitoring in the fumes, thermal efficiency calculations etc., flowrate detection for every single pass, thermocouples map on the ducts), immediately putting the plant in stand-by mode and the heater in safe condition, thus preserving and extending its lifetime. Additionally, proper redundancy is granted for all critical instrumentation and pumps.

The core of the plant is the DRI reactor, the pressure vessel where reduction of the oxides takes place. Its design is carried out by ENERGIRON specialists, while the manufacturing is normally performed in Danieli workshops, in accordance with the most stringent quality standards. In all ENERGIRON plants, whether they are Micro Modules of 200,000 tpy or Jumbo Modules of 2,500,000 tpy, the material flow, gas distribution and thermal profile are always kept in the optimal design range, guaranteeing a uniform high-quality product.

The above solutions are applied and well proven in all ENERGIRON plants, making ENERGIRON the only fully proven Direct Reduction technology for high capacity plants. Other similar technologies are only now beginning what ENERGIRON started 10 years ago with its high capacity plants, with many more challenges due to the lower operating pressure and bigger equipment size.
During the entire debugging phase for each one of the latest generation plants, the ENERGIRON team always remained by its Clients’ side to find a reliable and prompt solution to the unavoidable issues emerging during the first months of operation. The result of this team-up effort is that today these plants are consistently operating with standard operational availability and at the lowest OPEX for the entire Direct Reduction sector. There is no doubt that ENERGIRON stands unmatched in terms of energy efficiency, yield and product quality, providing the best product at the lowest operational cost.

In recent years, productivity of ENERGIRON plants has been negatively affected by low steel demand worldwide and, in the case of the Egyptian plants, also by lack of Natural Gas (NG) availability. In any case, plants availability is satisfactory and each plant produced at the desired rate.

In general terms, the inconsistent NG availability in Egypt is a major challenge for smooth operation of ANY Direct Reduction plant. Since the 2 ENERGIRON plants (SSC, ERM) have been lighted up for the first time, NG availability drastically changed from one day to the other, forcing operators to change process parameters and production rate over and over again to maintain the targeted DRI quality. As a matter of fact, only the ENERGIRON process proved to be able to operate successfully under these challenging conditions, thanks to its excellent flexibility.

However, most of ENERGIRON plants have been characterized by remarkable productivity and availability achievements during the last years.

From the currently operating 12 ENERGIRON modules, just in the year 2016, 6 plants have been operating at 100% or above nominal capacity; in some cases, up to 121% productivity. Ternium plants (3M5, 4M, 2P5), Lebedinsky, Hadeed and Emirates Steel are among these modules.

In terms of plant reliability, most of the plants have achieved between 95 and 99% availability with the exception of 2 modules, one in Abu Dhabi and the other in Louisiana.

Definitions as follows:

- Productivity: Actual Production / Target Capacity
- Operation Plant Availability: \[\frac{(\text{Calendar time } - \text{ Scheduled shutdown}) - \text{ Unscheduled shutdown}}{\text{Calendar time } - \text{ Scheduled shutdown}}\]

During the last 12 months, steel demand in the Gulf Area improved and ES targeted to increase the DRI output from its plants at nominal values. Since then, the ENERGIRON plants are working constantly at nominal capacity (2.0 Mtpy). Here below are summarized for reference the performances of ES-2 plant during last 12 months:

<table>
<thead>
<tr>
<th>Date</th>
<th>Production (t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun-16</td>
<td>250</td>
</tr>
<tr>
<td>Jul-16</td>
<td>200</td>
</tr>
<tr>
<td>Aug-16</td>
<td>150</td>
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<tr>
<td>Sep-16</td>
<td>100</td>
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<tr>
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</tr>
<tr>
<td>Mar-17</td>
<td>0</td>
</tr>
<tr>
<td>Apr-17</td>
<td>0</td>
</tr>
<tr>
<td>May-17</td>
<td>0</td>
</tr>
</tbody>
</table>

ENERGIRON plant at ES Phase 2: operating data during last 12 months. Courtesy of Emirates Steel.
The low utilization factor of direct reduction plants due to world steel downturn rewards those facilities capable of producing at lower OPEX. The selection of the best DR technology for a new plant shall consider the capabilities during the entire life (+25 years) of the plant:

- In terms of PRODUCTIVITY and availability, the mature ENERGIRON plants have demonstrated to be equal to or even better than mature plants based on any other competing technology:

For any direct reduction plant, the sum of iron ore pellet, natural gas and electricity costs accounts for more than 90% of the total DRI production cost. In terms of OPEX, ENERGIRON is by far the best performing NG based-direct reduction technology:

Iron Ore Pellet Consumption (Yield): thanks to the higher operating pressure, gas velocity through the reactor is minimized. Therefore, smaller pellets are acceptable (less screening losses) and material losses are minimized thanks to negligible dragging by off-gases. Remet generation is also minimized thanks to the possibility to bypass the reactor during the early stage of plant ramp-up. As result, the Yield of ENERGIRON Plants is unbeatable among the DRP technologies. Records of 1.35 t of Iron Ore Pellets per t of produced DRI have been repeatedly achieved.

Energy Efficiency: NG consumption for ENERGIRON III is as low as 2.6 Gcal/t and the energy of the steam in excess is recovered in order to produce or save electricity, leading to the lowest electrical energy consumption for any DR technology (in the range of 30 kWh/t). ENERGIRON ZR further improves the overall energy efficiency up to levels unattainable for any other DR technology. Since the reducing gases are generated inside the reactor, most of the energy supplied to the process is taken by the product, with minimum energy losses to the environment: as compared to other processes for which the overall efficiency is below 70%, for this scheme the efficiency is above 78%. This arrangement ultimately turns into very low natural gas consumption, even lower than 2.35 Gcal/t.

All above production charts are showing data published by the respective Plant Owner.
As the ENERGIRON brand may suggest, this technology is designed to produce DRI with high internal energy and value in use. ENERGIRON provides the flexibility to set the DRI characteristics as required by final user:

**METALLIZATION**: ENERGIRON plants can produce high quality DRI, with guaranteed metallization up to 96% (Nucor is the only plant in the world with guaranteed Met=96%).

**CHEMICAL ENERGY**: Carbon content is easily adjustable from 1.5 to 4.5%; up to 95% of which as iron carbide (Fe₃C), that provides additional energy to the EAF and stabilizes the DRI vs re-oxidation

To date, no other DR technology has proved to be capable of producing at industrial scale DRI with quality comparable to the ENERGIRON High-C DRI.

**THERMAL ENERGY**: the most efficient way to decrease the liquid steel production costs is to recover the thermal energy of the DRI and directly feed it to the EAF, still hot. ENERGIRON offers the most RELIABLE and EFFICIENT system to connect DRP and SMP up to 500m distance.

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### Performance and Reliability of ENERGIRON Plants

<table>
<thead>
<tr>
<th>UNIT</th>
<th>ENERGIRON III</th>
<th>ENERGIRON ZR</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUARANTEED CAPACITY</td>
<td>t/year</td>
<td>200,000 - 2,500,000</td>
</tr>
<tr>
<td>YIELD (IO/DRI)</td>
<td>t/t</td>
<td>&lt; 1.38</td>
</tr>
<tr>
<td>METALLIZATION</td>
<td>%</td>
<td>&gt; 94</td>
</tr>
<tr>
<td>NG CONSUMPTION</td>
<td>Gcal/t</td>
<td>&lt; 2.6</td>
</tr>
<tr>
<td>EL. ENERGY CONSUMPTION</td>
<td>kWh/t</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>OXYGEN CONSUMPTION</td>
<td>Nm³/t</td>
<td>0.0 - 7.0</td>
</tr>
<tr>
<td>CO₂ EMISSIONS¹</td>
<td>kg/t&lt;sub&gt;DRI&lt;/sub&gt;</td>
<td>256</td>
</tr>
<tr>
<td>NOₓ EMISSIONS²</td>
<td>kg/t&lt;sub&gt;DRI&lt;/sub&gt;</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Notes: 1. With selective removal 6 export. 2. Bat

All Energiron plants in operation proved to have lower consumptions than above nominal values.
CARBON IN EAF IS REQUIRED TO REDUCE RESIDUAL FEO IN THE DRI

TRADITIONAL DRI
- C = 1.5 - 2%
- 30% - 40% C in GRAPHITE form

LOW-C DRI
- GRAPHITE/COAL
- OXGEN E.E.

ENERGIRON DRI
- C = 1.5 - 4.5%
- C mostly in CEMENTITE form

HIGH-C DRI
- OXGEN E.E.

YIEL injected carbon < < 100%
- > Particles blowoff
- > Ash/impurities

YIEL carbon bond to DRI = 100%
- > ~ 33 kWh / t LS saved
- > ~ 10 Nm³ O₂ / 1% C

CARBURIZATION IN ENERGIRON PROCESS

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

T > 1050 °C
P = 6 - 8 BARG
CH₄ > 20%
H₂ / CO ≈ 5

operators that experienced the benefits of high c dri, never came back to traditional dri
(Ternium, Suez Steel, Nucor: all producing dri with >3.5%c)

CEMENTITE IS SOURCE OF ENERGY IN EAF

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

- For Fe₃C dissociation heat is:
  ~ 8 kWh / t DRI for each 1% Carbon
- Total: ~ 36 - 40 kWh / t DRI per each 1% Carbon in DRI

THERMAL ENERGY OF HOT DRI CAN BE RECOVERED BY TRASPORTING IN AT HIGH TEMPERATURE DIRECTLY FROM THE REACTOR TO THE EAF

> DRP & SMP AT THE SAME SITE

> SAVINGS FOR EVERY 100°C IN DRI:
- ELECTRIC ENERGY: ~ 26 kWh/t LS
- PRODUCTIVITY INCREASE: +5%

HYTEMP*: DRI T > 600°C AT EAF
- CONTINUOUS & INERTIZED FEEDING SYSTEM
- CLOSED & SEALED SYSTEM
- MAINTENANCE FREE
ENERGIRON finally is the technology better fitted for tomorrow’s challenges.

- LOWER OPEX: thanks to higher yield (<1.40), higher energy efficiency (NG <2.35 Gcal/t)
- HIGHER DRI QUALITY: high metallization (96%), wide C content (1.5-4.5%C)
- HIGHER INTERNAL ENERGY OF DRI: iron carbide (>95% Fe3C), Hytemp system (T > 600°C)
- HIGHER PLANT CAPACITY: proven up to 2.5Mtpy
- FLEXIBILITY IN REDUCING AGENT SOURCING: ready for Hydrogen/BFG/COG
- CO2 RECOVERY: intrinsic in process design
- REDUCED NOX EMISSIONS: elimination of reformer burners (ZR); adoption of BAT techniques
- NO CATALYST DISPOSAL: catalyst is DRI itself (ZR); in case of ENERGIRON III configuration, catalyst’s life is 3 times that of other processes (reformer operating with steam excess) and sensibly cheaper
EMIRATES STEEL SETS NEW RECORD IN DRI PRODUCTION

During the period of September 2016 through September 2017, Emirates Steel’s DRP #2 has set new production and availability records of more than 2,000,000 tons of high quality DRI, operating for more than 8,400 hours (equal to 105% net availability) and for 315 days continuously without any stoppage, confirming the reliability of the Energiron technology.

Emirates Steel operates in Abu Dhabi, two twin ENERGIRON DRI plants, originally designed for a nominal capacity of 1.6 Mtpy of hot and cold DRI at 94% metallization and 2.5% carbon. The first plant had been started-up in 2009, while the second one in 2011.

Both plants are designed under the ENERGIRON III process scheme and followed a smooth learning curve that resulted in 90% availability in the first three years for Plant #1 and 95% availability in only two years for Plant#2.

In 2014 both DRPs were upgraded from 1.6 to 2.0 Mtpy, reaching 100% stable production in only six months. Since then Emirates Steel is steadily operating the Energiron plants at their increased nominal capacity (2.0 Mtpy), producing high-quality hot DRI conveyed to the adjacent EAFs through the Hytemp pneumatic transport system, thus optimizing the downstream steelmaking process. ENERGIRON Team congratulates Emirates Steel on this remarkable achievement.

ENERGIRON is the result of the strategic alliance between Tenova HYL and Danieli to competitively serve the Direct Reduction plants market.
Look for Tenova HYL at the following events:

- **February 25-28**
  - **SME Annual Conference & Expo**
  - The Minneapolis Convention Center
  - Minneapolis - USA

- **March 4 - 7**
  - **CONAC 2018**
  - Cintermex
  - Monterrey, NL - México

- **April 25 - 26**
  - **Metall Bulletin’s World DRI & Pellets Congress**
  - Park Hyatt Dubai Creek
  - Dubai, UAE
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