HYLNEWS

JULY 2014

IN THIS ISSUE

- The Carbon Question
- How DRI Carbon Content Improves EAF Results
- DRI In Use – Emirates Steel Experience
- Alliance between ENERGIRON and Nippon Steel
- Calendar of Events

tenova HYL

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VIEWPOINT

In any business or industry, competition keeps all parties "on their toes", so to speak, and the customer is ultimately the one to benefit. Tenova HYL has always been dedicated to promoting its own positive features in the framework of a fair and honest competition.

When the question is raised "is too much carbon a problem?", it implies that anything more than a traditionally low amount of carbon must be bad, a leading question if there ever was one.

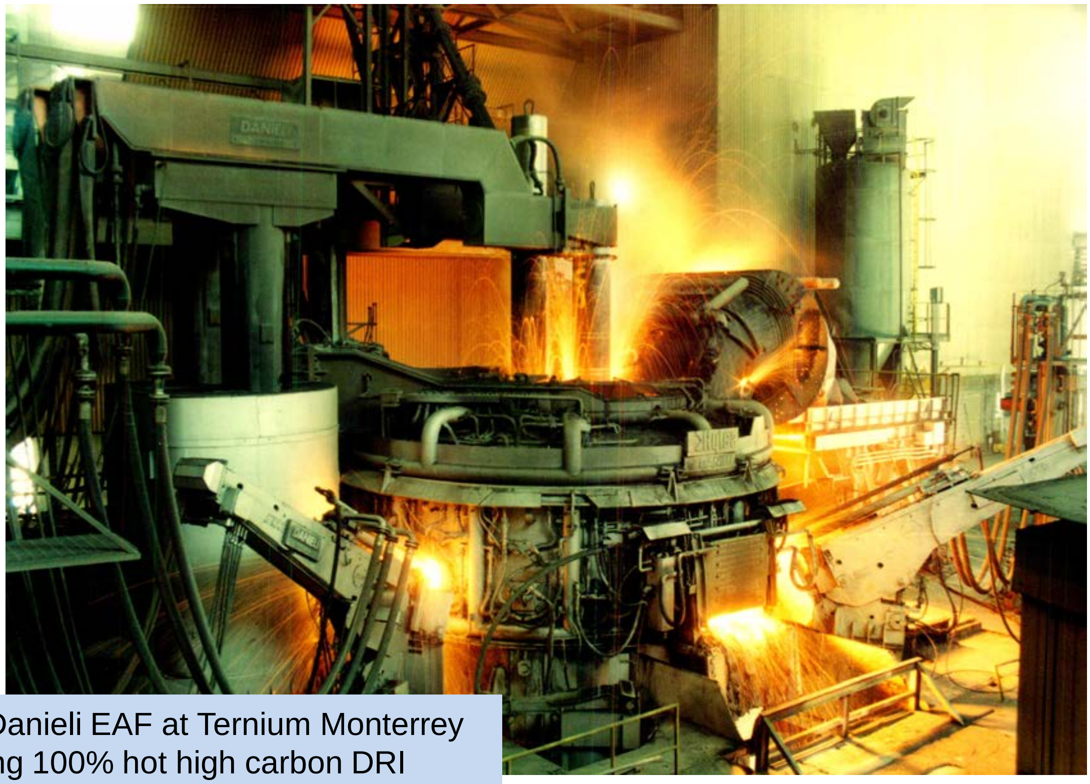
There has been some type of misinformation continuously growing, especially as our own success builds, so we thought it best to restate the facts, especially for the benefit of those who may not be familiar with the modern steel making practice in the EAF. The simple reality is that there is no universally correct answer when it comes to the right amount of carbon content in DRI; it all depends on the EAF practice and overall economics of the particular steel maker.

This issue of HYL NEWS discusses the difference between conventional and high carbon DRI and how it is made, as well as the benefits in the EAF. We show real results from real steel producers who are completely pleased with the product of the ENERGIRON process.

CONTENTS

2 Viewpoint
3 The Carbon Question
6 How DRI Carbon Improve EAF Results
8 DRI In Use – The Emirates Steel Experience
11 Alliance between ENERGIRON and Nippon Steel
12 Events Calendar

THE CARBON QUESTION



The Danieli EAF at Ternium Monterrey melting 100% hot high carbon DRI

Carbon in DRI and carbon in the EAF have both received a lot of attention in recent years. It is no secret that EAF practice involves carbon. Without carbon, there is no steel. The question is how to get the carbon into the EAF in the most cost-effective manner, and how to get the best quality and productivity from the steelmaking operation.

Before we can go any further, we have to define our terms. This is critically important since there are those who have chosen to confuse the issue by making false comparisons of unlike products.

Reduced iron products can have varying degrees of carbon, but not all reduction processes can achieve the same carbon levels.

PRODUCT DEFINITIONS:

DRI – Direct Reduced Iron, is made by removing the oxygen from iron ore (in the form of lumps, pellets or fines) by means of a reducing gas generally produced from natural gas or coal, or by direct contact with coal.

HBI – Hot Briquetted Iron is a compacted form of DRI designed for ease of shipping, handling, and storage in order to comply with International Maritime Organization shipping rules.

High Carbon DRI - Is a unique type of DRI that is characterized by having both high metallization and high carbon content (3 to 4.5%). What makes it unique is that the carbon is predominantly in the form of combined carbon or iron carbide.

For further clarification, we should also point out that DRI made in gas-based DR processes is generally expected to have a metallization level above 94% and typically has a carbon content of from 1% to as much as 3.0%. These levels of carbon in DRI are typical, able to be produced by the major reduction technologies, and are achieved in many different DR plant facilities worldwide. Therefore, to a certain degree it may be possible to compare them provided the circumstances and products are in fact the same.

However, since only the ENERGIRON ZR process can, to date, produce **High Carbon DRI,** and since it is such a unique product as compared to conventional DRI, any comparison can only be done for the purpose of confusing issues and misleading the reader.

PRODUCT BACKGROUND

The **High Carbon DRI** cannot be compared to conventional DRI for a number of reasons. First, as mentioned previously, it is only produced using the ENERGIRON ZR process. That is simply because the iron carbide formed during the process is the result of the reduced iron material being used as catalyst for the reforming and reduction reactions inside the reducing reactor.

These reactions effectively "contaminate" the catalyst with carbon, bonding it with the iron in combined form as Fe_3C. The typical range of carbon content in the reduced iron as the result of this process tends to be in the range of 2.8 to 5.0%, and as much as 80% of the total carbon in the product is in combined form, not as soot or free carbon.

To date, there are only 5 DR plants worldwide that produce **High Carbon DRI** : Ternium 3M5 and 4M plants, Monterrey, Mexico; EISCO in Abu Dhabi, Nucor Louisiana in the USA and Suez Steel in Egypt. Of these, only the 4M plant hot charges the **High Carbon DRI** to EAFs, the other three plants being cold discharge facilities.

There are other DR plants that hot charge directly to EAFs, but these generally have carbon content that can be up to 2.5%, on the "high end" in the category of standard DRI production. Good carbon content, but not what we would define as "high carbon" and since they are not ZR process plants, also not classed as **High Carbon DRI** producers. Examples are the Emirates Steel plants in Abu Dhabi. DRI produced at both facilities is typically 95% metallization and 2.0 – 2.5% carbon.

There are also a few EAF mills associated with our competitor's technology and that can or do feed hot DRI to their furnaces. However, by definition, these producers use a DRI product that at most has a carbon content of 2.5%, and most generally lower.

When we hear stories of steel makers being repeatedly unsuccessful at using hot DRI with "high carbon", our initial reaction is that they weren't properly trained by their technology supplier in the use of the product. When the conclusion is that the longer heat times were due to the excessive carbon content in the DRI instead of improper EAF practice, we know the problem is training, not the product itself. The problem is indeed systematic, but should not be blamed on the carbon level outright.

APPLES TO ORANGES

Referring back to the product definitions, one cannot simply compare a product such as High Carbon DRI to a conventional DRI product from a standard DR process. Because of the process configuration, the standard non-pressurized reformed gas-based process can produce DRI with higher carbon levels only by increasing the residence time and flow of natural gas to the cooling zone of the shaft furnace. This does increase carbon, but not in the same way as with the High Carbon DRI produced by ENERGIRON. Rather than producing a combined carbon or iron carbide, it simply increases the amount of free carbon or soot on the surface of the DRI. So when one attempts to compare the behavior of the two types of DRI, it becomes deceptive to say that they will both react in the same way in an EAF environment.

Secondly, to argue that *"the hotter the DRI, the less carbon that can be utilized"* completely ignores the fact that an experienced steel producer knows how to combine the benefits of both hot DRI and high carbon DRI to maximum advantage. Again, this is true for any carbon level – from medium or conventional DRI carbon levels, up to truly high carbon (iron carbide-type) products.

The ONLY plant in the world currently producing and melting hot, high carbon DRI is the Ternium 4M plant in Monterrey, Mexico. Of the two furnaces, one melts 100% hot DRI and they insist on carbon of 4.2% from the DR plant.

Emirates Steel is also uniquely experienced in melting hot DRI in both their melt shops and with world record productivity unmatched to date by any other company (see accompanying article). They are experienced in using varying degrees of carbon depending on their objectives, so the idea of *"one carbon level fits all"* is hardly correct.

Nucor Louisiana of course produces cold DRI but insists on carbon of 4.2% and metallization of 96% for their mills. Apparently, when you know how to use carbon, it's not the problem some would like to have you believe. Simply put, the experienced operator knows how to handle both temperature and carbon, so instead of being a problem, it is a unique benefit when using the proper EAF practice.

So when confronted with the carbon question, it is fair to as "if high carbon is a problem, why is pig iron so popular"? Carbon content levels in Pig Iron are very similar to those present in the high Carbon DRI offered by the ENERGIRON ZR Process (3 – 5%), many have realized about the benefits of using this technology and as the success of these companies builds we are sure many others will join.

DRI Analysis – Nucor DR Plant:		Conventional DRI analysis:	
Metallization	96%	Metallization	94%
Carbon	4.3%	Carbon	2.2%
Fe°	87.3%	Fe°	89.2%
Fe Total	90.9%	Fe Total	92.9%
Fe_3C	58.5%	Fe_3C	29.6%
Gangue	3.8%	Gangue	3.9%

HOW HIGH CARBON DRI IMPROVES EAF RESULTS

As has been previously indicated, the ENERGIRON-ZR Process favors the diffusion of carbon in the Iron matrix and the precipitation of Iron Carbide (Fe_3C). This type of product presents numerous advantages. For example, DRI with a high content of Fe_3C exhibits a much lower reactivity (no gas generated in any test conducted) than does standard DRI. This has been proven in various independent tests, but for now we will limit ourselves to discuss the behavior of high carbon DRI in EAF steel making.

There is additional energy required to produce 3.5-4% carbon in the DR plant. However, that energy is marginal; In any case, by reducing carbon in the DRI, more CO_2 will be taken out through flue gases/CO_2 removal system. So the better option is to produce high-carbon DRI and provide additional chemical energy to the EAF.

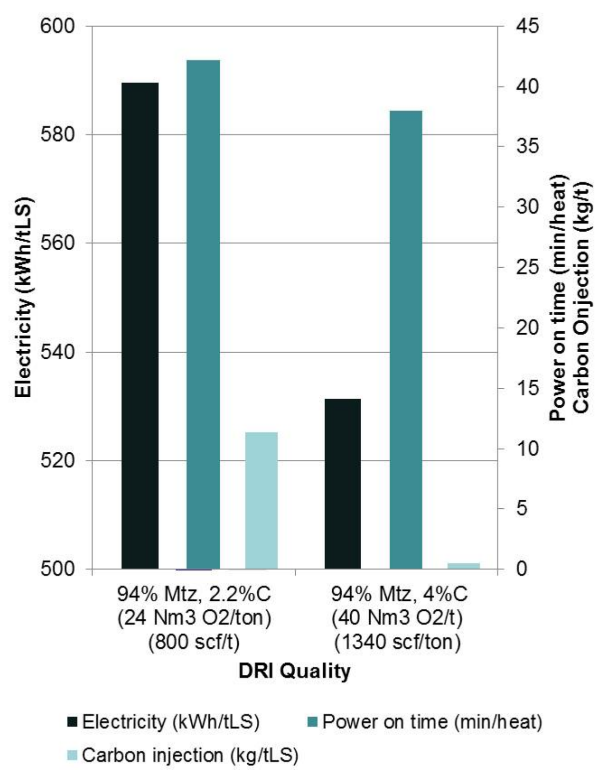
Since DRI is an input for steel making, if it has a marginally higher cost but produces a lower cost, higher quality steel as a result, then the initial cost is easily justified. Let's look at some comparisons based on actual experience and not conjecture.

Effect of DRI Carbon – 100% cold DRI
Let's look first at the effect of cold DRI carbon in the EAF in order to isolate it from the added beneficial effects from high temperature.

DRI with high carbon contains additional energy as compared to the standard DRI, thus reducing the electrical power consumption and increasing productivity in the EAF. An added benefit is also a reduction or elimination for the need of additional carbon injection to the EAF.

Most of the carbon in DRI made with the ZR Process is in the form of iron carbide. This provides approximately 33-37 kWh/tLS of energy for each 1% of carbon in the DRI.

Obviously, to take advantage of this chemical energy potential, it is necessary to use oxygen; this amount is typically around 10 Nm^3 of O_2 for each additional 1% of carbon (335 scf/ton).



The chart shows a comparison of DRI of the same metallization (94%) for both cases, varying the carbon content from a fairly standard 2.2% to 4% in the second test. As mentioned, oxygen requirement increases based on the increased carbon but the important take-away is the significant reduction in electricity needed for the 4% carbon DRI melt. Power-on-time is also decreased, increasing productivity at a lower overall cost per heat.

These are readily seen economic benefits to be had just by using increased DRI carbon content. Other benefits include:

- Oxygen is injected to match the Carbon input (from DRI) and controlled according to the DRI feeding rate
- Carbon and Oxygen are continuously added throughout the complete heat
- high CO generation provides easy to create and maintain foamy slag throughout the melting process
- Carbon in the DRI is pure; no presence of ashes, sulfur, volatile matter, etc.
- Carbon in the DRI minimizes/eliminates the use of external carbon
- Carbon is fed without any carrier gas
- Carbon in DRI has a higher yield than injected carbon
- DRI chemical analysis is totally known and the behavior can be 100% predicted.

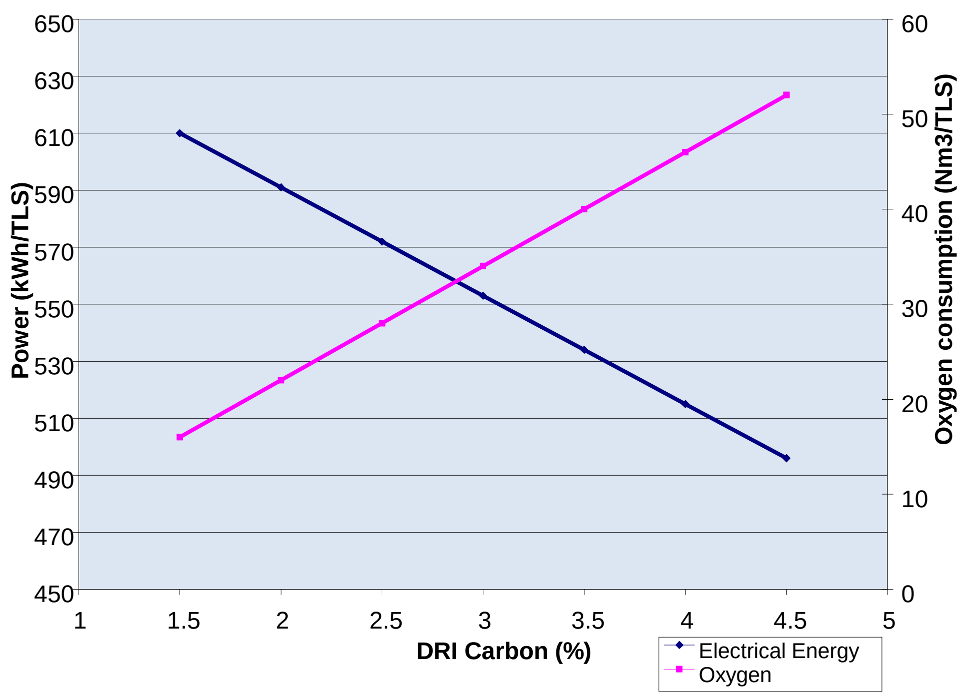
The Carbon in DRI is source of energy by the following main reactions:

$$2C + O_2 \rightarrow CO \quad + \text{Heat}$$

$$Fe_3C \rightarrow 3Fe + C \quad + \text{Heat}$$

The chart below shows clearly how as the amount of carbon in the DRI increases, the energy consumption decreases, but at the same time the O_2 required to utilize this energy increases as well. This, as stated in the beginning, depends on the EAF practice and overall economics of the particular steel maker.

In the next issue of Tenova HYL News we will explore another factor that combined with the High Carbon content in the DRI gives an edge for the steel production: High Temperature.



DRI IN USE – DIFFERENT PLANTS, DIFFERENT SOLUTIONS

By Appala Naidu Poodi, DRI Plants Manager, Emirates Steel

If one seeks out a company to benchmark steel productivity, it would be hard to find a better reference than Emirates Steel of Abu Dhabi. Both the Phase 1 and Phase 2 steel making plants are proof positive of the benefits of hot charging DRI for EAF steel making with higher than typical levels of carbon.

This article is based on a presentation made at the Metal Bulletin 1st World DRI & Pellet Congress last April 2013 in Abu Dhabi.

Emirates Steel is wholly owned by SENAAT, the UAE's largest industrial conglomerate and a driving force for implementing the Abu Dhabi government's industrial diversification policy.

Strategically located in the Industrial City of Abu Dhabi, in Musaffah, Emirates Steel is the only integrated steel plant in the UAE, utilizing the latest technology to produce high quality rebar, wire rod and heavy sections.

Established in 1998, Emirates Steel grew in a relatively short period of time from a simple re-roller of imported steel billets to a complex integrated manufacturing plant. In 2012, the company achieved a capacity of 3.5 million MTPA, following two expansions and an investment of AED 10 billion (US$ 2.72 billion).

The complete complex was a turnkey project built by Danieli that includes 2 ENERGIRON DR plants with HYL HYTEMP Pneumatic Transport systems for hot feeding of high carbon DRI to the melt shops. The DR plants were originally designed to produce 1.6 million mpty of DRI each, both hot and cold discharge, and have been expanded to 2.0 million tons each. The wide flexibility in ore use is illustrated by the mix of (to date) 7 different iron ore sources, both pellet and lump.

The two steel making plants were also expanded from their original 1.4 million tpy to 1.7 million tpy.

The standard operation of the plants is the use of 100% DRI to the two Danieli furnaces. The chemical analysis of the DRI is shown in the table, typically with carbon content of 2.2 – 2.5% and fed hot to the EAF.

DRI CHEMICAL ANALYSIS	
CHEMICAL ANALYSIS	RANGE %
Iron (Fe total)	91.5 - 92.0
Iron (Fe metallic)	86.0 – 88.0
Metallization %	94 -95.5
Silicon Di Oxide (SiO2)	1.7 -2.0
Aluminium Oxide (Al2O3)	0.6 - 0.8
Calcium Oxide (CaO)	0.8 - 0.90
Magnesium Oxide (MgO)	0.1 - 0.4
Carbon	2.2 – 2.5
Sulphur (S)	0.007 -0.01
Phosphorus (P)	0.04 -0.05

USE OF HOT DRI IN THE EAF

Emirates Steel uses hot DRI feeding to the EAF to obtain maximum benefits in steelmaking (see EAF characteristics table below). Among the benefits obtained are:

- Availability—unlike low residual scrap supply, which is limited, the supply of DRI can be increased according to the demand.
- Associated carbon—DRI has the added benefit, when compared to scrap, that it contains an associated energy value in the form of combined carbon which increases furnace efficiency.
- Direct charging—the use of hot DRI directly transported and charged to a furnace, can reduce energy consumption by as much as 16 to 20% by making use of the energy value of the DRI at temperatures greater than 450° C.
- The price for DRI is basically open to negotiation with the producer, unlike scrap prices, which are routinely published by grade and market. Generally DRI be at a price equivalent to that of premium low residual scrap grades.
- DRI plant construction is less time consuming, sometimes less than two years, as compared with 5 to 7 years for a blast furnace/BOF facility.
- Several DR plants have been constructed in less than 3 years and have reached design production rate within 30 days after start up.
- More environmentally friendly—avoids problems of hazardous contaminants such as lead or cadmium in EAF dusts.
- Blending abilities of DRI with scrap allow cheaper, low quality scrap grades to be used.
- Material free of residual elements: DRI is free of residual elements so higher quality steel grades can be produced.
- Higher volumetric weight: with a volumetric weight varying from 10 to 100% higher than of different types of steel scrap, DRI allows a denser charge into the furnace, avoiding at least one scrap recharge. In the case of basket feeding, and assuming 25% DRI in the metallic charge, this helps avoid radiation heat losses and reduces the tap-to-tap time.
- Material with less undesirable elements: Sulfur and phosphorus content are very low, allowing shorter refining time in EAF.
- DRI can be continuously charged: Continuous charging reduces the melting and refining time, eliminates scrap recharge into the furnace and allows a faster tap-to-tap time. DRI systems are simpler and easier to operate and maintain.
- Uniform chemical analysis: This avoids product quality deviations and provides predictability to the steel making process.
- Less flicker: The granular uniformity of DRI yields a more uniform power, reducing flicker to less than half of that experienced during scrap melting. Power uniformity also avoids electrical interruptions and discontinuities presented during scrap melting, giving an advantage power of about 5% higher.

Steel Making Plant: 1.4 million TPA

ITEM	MAIN DATA
ELECTRIC ARC FURNACE	
EAF Type	AC, split shell, EBT system, conductive arm, DANARC module
Tapped steel	150 tons
Transformer size	130 MVA + 20%
Tap-to-Tap time	46 min
EAF hourly productivity	195.7 T/H

- Easier foamy slag generation: DRI carbon enters in contact with free or combined oxygen, it generates CO in the slag-bath interphase. The CO goes through the slag producing the foamy effect making more efficient the energy transfer to liquid steel and protecting the furnace walls. This effect to achieving during continuous feeding of DRI since CO is generated through the continuous feeding period.
- Better bath stirring : The generated CO content in liquid steel and allowing better heat transfer efficiency due to the generation of foamy slag.
- Lower Nitrogen content : ~ 20 ppm or lower of N2 for more DRI.

HOT DRI TRANSPORT VIA THE HYL HYTEMP SYSTEM

Tenova HYL started HOT DRI Pneumatic Transport System in 1997. This system is called HYTEMP to fulfill the logistical requirement of Hot DRI. The HYTEMP System delivers Hot DRI to the Melt Shop. The System connects the Reactor discharge to the melt shop via a pneumatic transport pipe which delivers hot DRI to the EAF.

The system operates by using a transport gas (inert gas) to carry the hot DRI through a pneumatic pipe to a surge bin above the electric furnace. The transport gas is removed from the circuit and recycled back to the DR plant and the hot DRI is charged to the surge bin for continuous feeding to the EAF.

By using hot DRI in the EAF via the HYTEMP System, Emirates Steel has shown both a lower energy consumption and also a 20% productivity increase. Delivery of hot (500° C) high carbon DRI to the EAF significantly reduces power requirements for melting, thus lowering tap-to-tap times.

Based on the typical DRI characteristics at Emirates Steel of 95% metallization and 2.5% carbon content, the positive results of feeding hot high carbon DRI as compared to cold DRI is shown in the table. Clearly, a double advantage for using hot, high carbon DRI.

	UOM	Cold DRI	Hot DRI	Saving ($/t of billet)
Reduction Electricity Usage	Kwh/t	508	413	3.9
Reduction in Power On Time	Min/Heat	44	36	4.7
				8.6
Total saving on 1.4 Million ton			**USD**	**12,000,000**
WORKINGS	**Unit**	**Cold DRI**	**Hot DRI**	**Difference**
Tap to Tap time	Min	57	48	9
Total Time	Min	1440	1440	-
No of Heats	No	25	30	(5)
Fixed Cost Saving	$/t	30	25	5
Higher Production	Tons	1,174,737	1,395,000	220,263
Margin	**$/t**			**50**
Total Savings			**USD**	**11,013,000**

ALLIANCE BETWEEN ENERGIRON PARTNERS AND NIPPON STEEL

DRI FOR INTEGRATED APPLICATIONS

Tenova HYL and Danieli & C, have entered into an agreement with Nippon Steel & Sumikin Engineering Co., Ltd. (NSENGI) to combine and commercialize their Energiron DR technology with an optimized blast furnace technology, as well as syngas technology (high efficiency coal gasification and steelworks by-product gas utilization technology) developed and owned by NSENGI.

The two key areas of combined know-how involve the integration of the Energiron Direct Reduction technology with the blast furnace as well as the areas of interface between existing and future syngas technologies with the Energiron process.

The charging of specialized DRI to the blast furnace, produced by Energiron with high carbon content and its reduction ratio adjusted, will target a significant decrease in the blast furnace production cost in comparison to the conventional DRI charging to the blast furnace method.

This new alliance will allow the three parties to combine research and development activities with their respective expertise in Energiron DR, blast furnace and syngas technologies, with the ultimate objective of developing a new iron making technology which will reduce CO_2 emissions and operating costs, while increasing productivity and/or decreasing capital expenditures for integrated steelmaking facilities. Such includes execution of EPC projects by the parties in connection with the above collaboration.

In addition, the optimized combination of Energiron Direct Reduction technology and syngas technology (high efficiency coal gasification and steelworks by-product gas utilization technology) will enable Energiron Direct Reduction plants to have access to non natural gas sited customers.

The alliance also provides for the joint marketing of existing direct reduction technology to blast furnace customers.

The alliance formed by Tenova, Danieli and NSENGI seeks to capitalize on key advantages of Energiron, which in addition to capacity also include environmental and economic benefits beyond those offered by existing technologies.

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CALENDAR OF EVENTS

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JUNE – DECEMBER 2014

Look for Tenova HYL at the following events:

June 16 - 18
AMM & World Steel Dynamics' Steel Success Strategies XXIX
Sheraton New York Times Square Hotel
New York, NY, USA

August 1
SIMA 2nd India International DRI Summit 2014
Hotel Le Meridien
New Delhi, INDIA

September 10 - 11
AMM 2nd Mini-mills & DRI and 8th Steel Scrap Conferences
Hilton Riverside Hotel
New Orleans, LA, USA

November 9 - 11
Latin American Steel Congress & Expo Alacero-55
Hotel Hilton Reforma
Mexico City, D.F., Mexico

November 19 - 21
AIST DRI: Logistics, Production and Utilization Seminar
Roosevelt Hotel
New Orleans, LA, USA

December 8 - 10
Metal Bulletin 18th Middle East Iron & Steel Conference
Atlantis, The Palm
Dubai, UAE

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