FLEXIBLE AND RELIABLE DIRECT REDUCTION PLANTS THE KEY FOR ECONOMIC DRI/HBI PRODUCTION

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ABSTRACT

Direct Reduced Iron (DRI) and Hot Briquetted Iron (HBI) are premium sources of metallic iron units for the electric arc furnace, due to their nature as virgin iron units, with a high content of metallic iron, a controlled amount of iron carbide, and practically free of residual elements.

About 80% of the world DRI/HBI capacity (90% actual production) is shared by two natural gas-based processes. One of them is the HYL direct reduction technology, which has demonstrated its flexibility and reliability through the operation of different industrial plants worldwide.

Since 1979, Ferrostaal has developed and built HYL DR plants in Mexico, Indonesia, Malaysia and Russia, for a total capacity of 5.5 Million ton/year of DRI/HBI. All of these projects were specifically adapted to the particular conditions and needs of each user and the DR plants have fully proven their reliability through their operating performance.

This paper describes the characteristics and features of HYL DR plants built by Ferrostaal, indicating the flexibility of the HYL technology and the capabilities of Ferrostaal as General Contractor for an optimum project development. A description of the latest FS/HYL developments, such as the self-reforming process and the optimized Mini-Module concept is also included.

Keywords: DR, DRI, HBI.

Paper presented at XXXII ABM Iron-making Seminar, November 6-8, 2002-Vitória-ES, Brazil
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INTRODUCTION

Direct Reduction (DR) consists in the removal of oxygen from iron ores at temperatures under the melting point of the solid material, for the production of a product with a high content of metallic iron and a certain level of carbon mainly as iron carbide (Fe_3C). This product is named Direct Reduced Iron (DRI). Hot Briquetted Iron (HBI) is produced increasing the DRI density, by applying pressure at high temperature (700 °C). HBI is more commonly used on a merchant basis for export and can also be produced when friable iron ores are to be processed, and these ores cannot be used for the production of cold DRI due to the high fines generation.

The three main chemical factors used to characterize DRI/HBI are the metallization level (metallic iron/total iron), the content and form of carbon, and the content and type of gangue (non-ferrous oxides). The typical metallization levels in modern DR processes vary in a range from 92% to 95%, whereas the DRI carbon content can be controlled up to 5.0% (HYL Process) mainly in the form of iron carbide (Fe_3C). The content of residual elements such as Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo) and Tin (Sn) is normally very low (traces) in DRI/HBI. Non-metallic impurities, normally present in steel scrap, are also absent in DRI/HBI.

DIRECT REDUCTION TECHNOLOGY AND PLANTS

The evolution of direct reduction technologies to the current situation has involved hundreds of different DR process concepts, many of which have operated experimentally at lab or pilot scale levels. Most were found to be technically or economically unfeasible and thus abandoned. Nevertheless, some other were successful and then subsequently improved to develop into full-scale commercial operation. However, even some of those which reached the industrial scale level could not achieve either their technical or economical parameters and have been also abandoned. Several cases have been experienced, where such developments disappeared at an advanced stage, after long time efforts and significant capital expenses. This is not only costly for the developer, but also for some other companies that are normally involved in the project as investors- later without success.

As explained, the development of new DR processes needs a long time and significant capital expenses. An investor who is willing to develop new DR technology must also consider the real potential to compete in the market, mainly if other processes already exist and are commercially proven. In this case, a new DR technology must offer significant economic advantages, such as lower energy consumption, lower investment costs, higher product value, or a higher flexibility for using cheaper raw materials and reducing gases.

At the beginning of the new millennium, the two world leading direct reduction technologies are gas based-processes, which operate under a moving bed reactor (shaft furnace) concept for iron ore reduction; Midrex and HYL. Both technologies use as raw material DR grade-pellets and lump ores, and have proven extensively their economic results and plant reliability, reaching a plant availability higher than 90%. The process steps are completely developed and are highly flexible.

Industrial plants based on these two technologies produce about 90% of the total DRI/HBI of the world. The application of any of these technologies in a new plant will offer minimum risk to the investor, unlike the case when new commercially unproven technologies are used.

Some new or “improved” DR processes have come recently into the market, with claims about advantages on the DRI/HBI production costs and a higher product quality. However, industrial plants have not fulfilled the expectations and the process performance has yet to be demonstrated on a continuous basis. Projects based on these technologies have exceeded by far the capital budgets, implementation time-schedules, start-up curves and expected operating costs.

The success in DR plants operation is not only related to technological issues. The capability of the General Turnkey Contractor and an efficient technology transfer process are of prime importance. The strict monitoring and control of the project schedule and milestones, a clearly defined communication, both internally within the project team, and externally with the client and the nominated subcontractors are essential activities. Quality and delivery are obviously key issues and have to be strictly monitored and controlled from material sourcing and throughout the manufacturing phase. The interfacing with the building, civil and service contractors is also a key area, in order to ensure the accurate and timely provision of building structures, foundations and services, aligned with the core plant requirements. Finally, the process of plant installation and commissioning is an area where extensive planning and scheduling is required. The detail scheduling of the installation process and the allocation of adequate resources–supervisory management and labor is obviously critical to the project success. All this comprises the role of Ferrostaal as Turnkey Contractor for HYL direct reduction plants worldwide.

HYL DIRECT REDUCTION PROCESS

The HYL direct reduction process was the first technology to operate successfully at industrial scale in the world (1957), proposing a technological concept that was a real solution to the metallic needs of Hylsa in Mexico. Based on a fixed bed reactor concept, the results achieved with this technology were so attractive and innovative that other steelmaking companies acquired the HYL process license. 22 reduction units were installed in different countries, for a total capacity of over 9 Million ton/year of DRI. However, it was foreseen by HYL that the competitiveness of this technology would be limited due to its batch nature. For this reason, a research program was initiated in 1967 to develop a continuous (moving bed) process, starting the first industrial plant in May, 1980 in Hylsa Monterrey, Mexico. The new process concept led to higher plant productivity, superior DRI quality, lower energy consumption and a simpler plant operation.

Through the years, several improvements have been incorporated in the HYL moving bed process (Figure 1). In 1986 a CO_2 removal system was incorporated in the reducing gas circuit, allowing significant improvements in productivity, energy consumption, and DRI quality. In industrial operations, the reformed gas consumption was decreased by about 50% and the reactor productivity was increased by a similar figure.

In 1995 the partial combustion technique was applied in HYL industrial plants, injecting oxygen at the transfer line between the reducing gas heater and the reactor inlet. This scheme allowed an important increase in the reducing gas temperature, as well as in-situ reforming, decreasing the reformed gas consumption by about 25%, combined with increased reactor productivity. In 1988 the total natural gas feed and oxygen injection to the reduction reactor led to the "HYL Self-Reforming scheme", where the reformed gas make-up is decreased to zero. This scheme is in successful industrial operation in the Hylsa 4M plant since April, 1998, and in the Hylsa 3M5 plant since July, 2001.

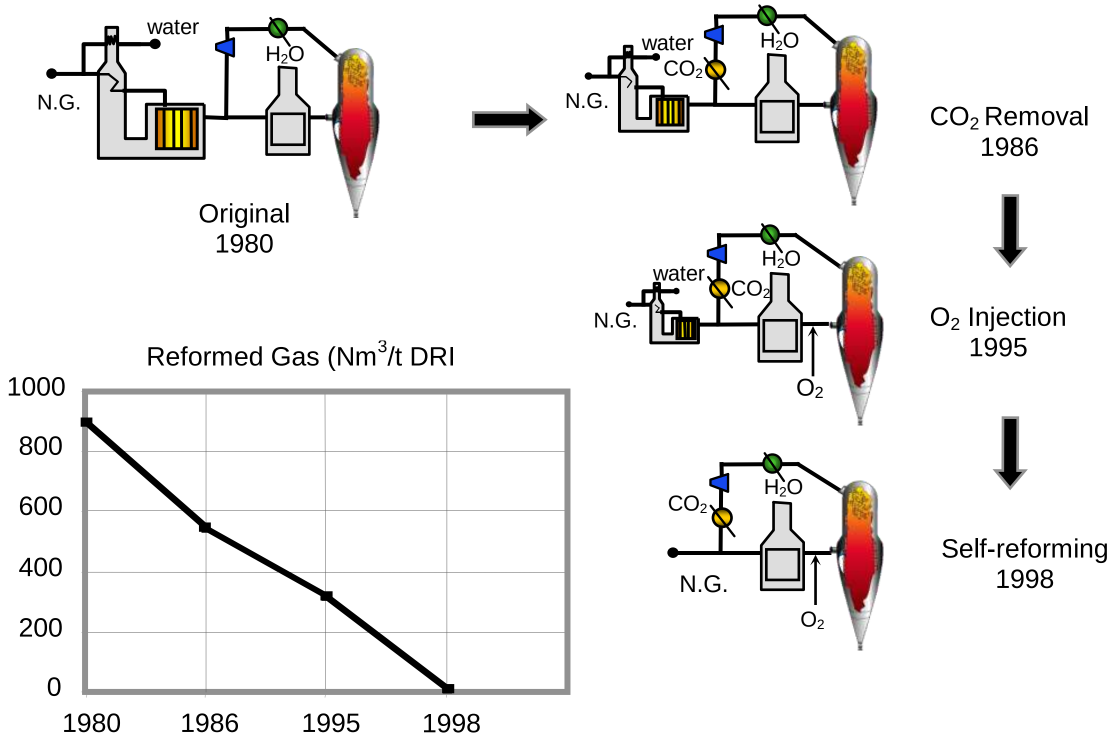

Figure 1. HYL Process Development

A general diagram of the HYL process is presented in Figure 2. The HYL process is designed for the conversion of iron ore (pellet/lump) into metallic iron, by the use of reducing gases in a solid-gas moving bed reactor. Oxygen is removed from the iron ore by chemical reactions based on hydrogen (H_2) and carbon monoxide (CO) for the production of highly metallized DRI/HBI.

The technology offers the flexibility to produce three different product forms, depending on the specific requirements of each user. Reducing gases are generated by self-reforming in the reduction reactor. Natural gas is fed as make-up to the reducing gas circuit and oxygen is injected at the reactor inlet. The partial oxidation of natural gas with oxygen generates reducing gases in-situ (H_2 and CO) and increases the operating temperature, which is required for reforming and iron ore reduction. Once in contact with the solid material inside the reactor, further reforming and cracking are carried out due to the catalytic effect of metallic iron. Alternative sources of reducing gases can be used in HYL plants, such as reformed gas, coal gas, and others, under the same basic process scheme.

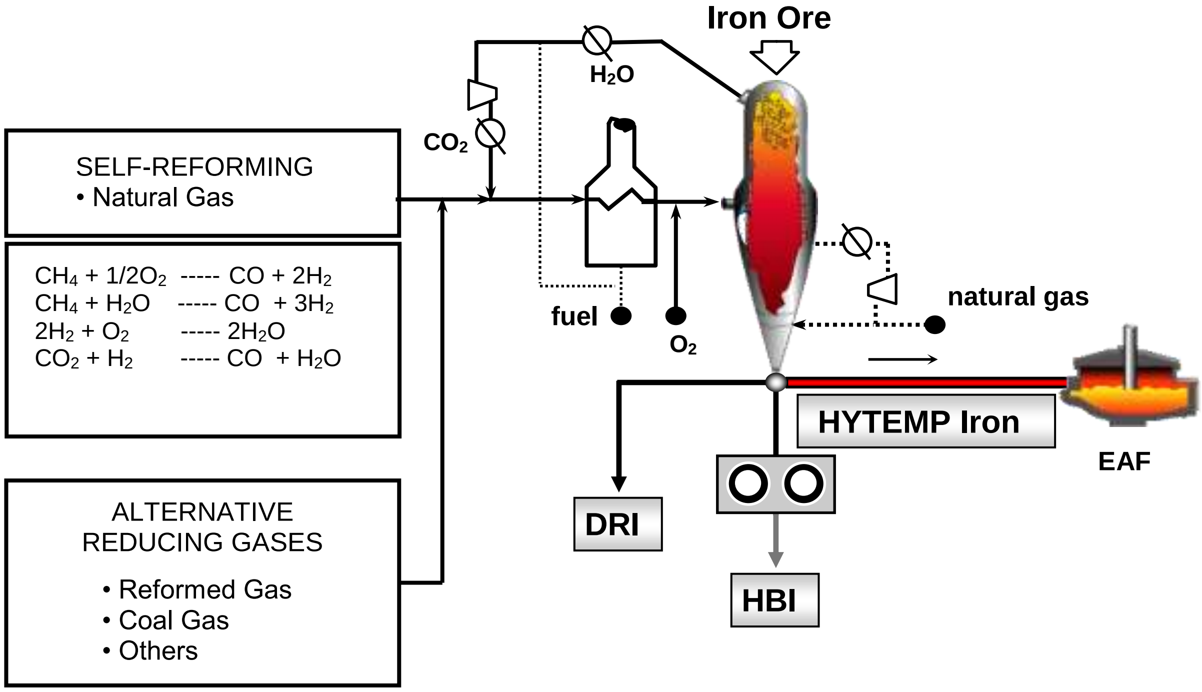

Figure 2. HYL Process Diagram

IMEXSA, LAZARO CARDENAS, MEXICO, 1988, 1990

The first HYL moving bed plant outside Hylsa was built by a Consortium formed by Ferrostaal AG and MAN-GHH of Germany, for the Government owned Mexican steelmaker, Sicartsa. The plant was privatized in 1992 and acquired by the Ispat group. The new plant was named Ispat Mexicana S.A. de C.V. (IMEXSA).

The plant, located in Lazaro Cardenas, Mich., Mexico, has a nominal production capacity of 2.0 Million ton/year of DRI, operating with four moving bed reduction reactors and two reformers (two modules).

One reformer serves two reactors, and each reactor is directly connected to one reducing gas heater. Main equipment and auxiliary systems serving the two modules are the following:

- Iron ore and DRI handling/storage systems.
- Inert gas generation unit.
- Water treatment plant.
- Cooling water systems (process & equipment).
- Instrument air system.
- Electrical equipment.
- Control system.

In the IMEXSA plant, the CO_2 absorption unit was not incorporated in the reducing gas circuit, as the plant was designed in 1980, when this process scheme was not yet in industrial operation in HYL plants. Energy integration in the process scheme with CO_2 removal is optimized generating steam for the CO_2 desorption unit, by recovering energy from the reformer combustion gases. In case of IMEXSA, without a CO_2 removal unit, the specific energy recovery scheme was based on an integrated reformer-gas heater arrangement (Figure 3), where a fraction of the recycled reducing gas stream is preheated in the reformer convection section, recovering sensible energy from the reformer combustion gases. Final heating is carried out in the reducing gas heaters (one for each reactor). The combined efficiency of this reformer-heater arrangement is over 91%.

The plant was erected on an area of 77,000 m^2. The four reduction reactors were allocated inside a common reactor tower. The associated reformers and gas heaters are arranged along side of the reactor tower. Critical plant components are driven by steam turbine to provide safety from external power failures, with the necessary steam being generated in the process itself. This allows keeping the reformers in operation also in the event of electricity supply failures, thus avoiding critical temperature shocks for the reformer tubes. The plant is fully automatic and was equipped with an advanced distributed digital process control system, so that interventions by control room personnel are only necessary in case of problems of failures.

Completion and commissioning of the DR plant were delayed, due to external circumstances such as the Mexican indebtedness crisis and the 1985 earthquake. Therefore, Module 1 was started up in 1988 and Module 2 in 1990. The IMEXSA HYL plant has operated with a wide variety of raw materials, including 10 pellets and 4 lump ores. However, since the start up of their own pelletizing plant in 1997 (using Brazilian pellet feed), the HYL modules have been basically operating with a mixture of local raw materials, Peña Colorada and IMEXSA pellets. From 1995 to 2001, the HYL IMEXSA plant has produced high quality DRI with an average productivity of 108%.

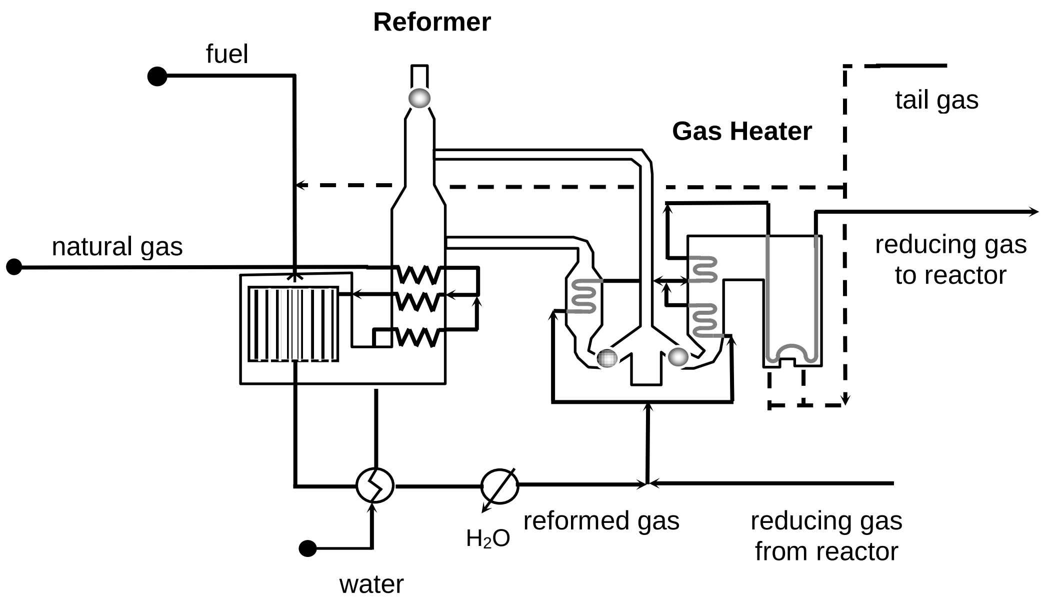

Figure 3. IMEXSA Plant-Integrated Reformer-Heater Arrangement

P.T. KRAKATAU STEEL, CILEGON, INDONESIA, 1993

In August 1990, Ferrostaal AG, MAN-GHH, P.T. Krakatau Engineering Co. and Hylsa S.A. received an order for the construction of a direct reduction plant, based on the HYL moving bed process. The customer was an Indonesian Government owned company, P.T. Krakatau Steel (PTKS), the country's largest steel producer. PTKS has been operating, since the 1970's, an iron and steel mill in the coastal town of Cilegon (120 km west of Jakarta). The original plant was built by Ferrostaal AG as general contractor, incorporating four HYL fixed bed plants and two steel plants, for which MAN-GHH supplied eight electric arc furnaces.

The modernization concept entailed linking the new plant to the old one using some of the existing equipment. One of the four HYL fixed plants was decommissioned. Only the corresponding reformer and general services were used for further operation with the new HYL moving bed reactors. With the existing reformed gas capacity, which previously was only enough for the production of 500,000 ton/year of DRI, two HYL moving bed reduction units are currently producing over 1.35 million ton/year of DRI. The moving bed reduction units achieve considerably better chemical utilization of the reducing gas than the fixed-bed reactors previously used. Moreover, the incorporation of a CO_2 removal system assures that the reducing gas constituents are fully recycled for optimum plant productivity. DRI produced in the HYL moving bed plant has higher metallization, higher carbon, and uniform quality.

The main scope of the turnkey plant order included two reduction reactors, two gas heaters, three process gas screw compressors for the reducing gas and cooling gas (supplied by MAN-GHH), and the material handling equipment for the iron ore pellets, lump ore and DRI. The plant fulfills the most stringent environmental standards and earthquake safety requirements

The moving bed reduction units were started-up at the end of 1993 and increased the PTKS DRI capacity over 2.8 Million ton/year. The HYL moving bed plant set an annual production record in 2001, achieving a plant productivity of 110%.

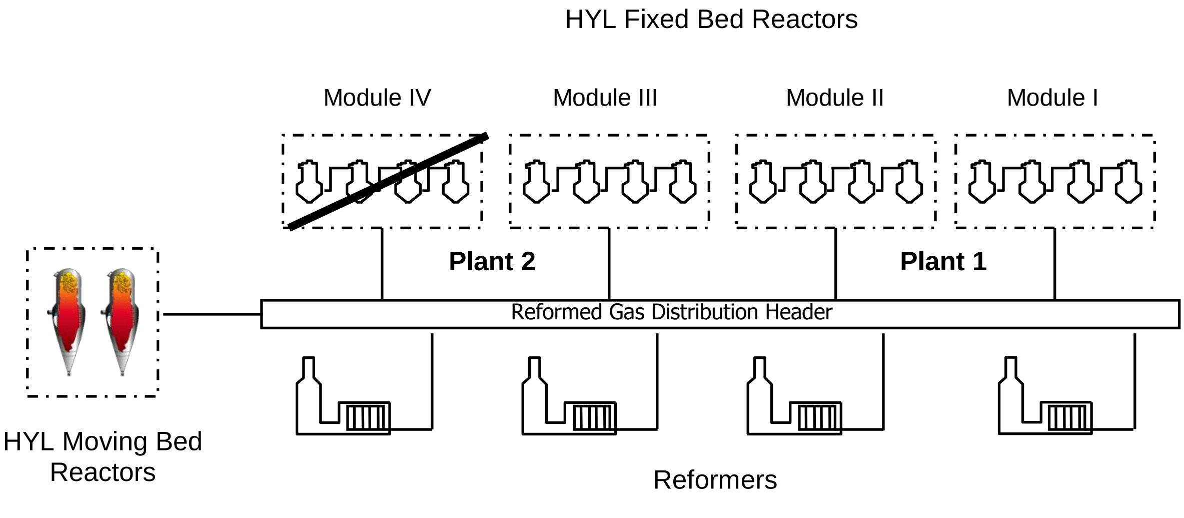

Figure 4. Conversion of the PTKS DR Plant

PERWAJA STEEL SDN. BHD., KEMAMAN, MALAYSIA, 1993

Since 1984, Perwaja Steel Sdn. Bhd. (PSSB) has been operating an iron and steel mill based on the direct reduction-electric steelmaking process route in the Malaysian federal state of Trengganu, some 350 km to the north-east of the capital, Kuala Lumpur. The original direct reduction plant, using a DR Japanese process here for the first time on a commercial scale, was shutdown after it had failed repeatedly to attain the guaranteed performance levels. In September 1990, a consortium consisting of Ferrostaal AG, MAN-GHH, and Hylsa S.A. received an order to convert the plant for increasing the plant capacity from 600,000 to 1,200,000 ton/year of DRI, using the existing reformer and part of the general services and infrastructure.

The first step in the modernization involved systematically inspecting the idle plant. Based on these activities, the repair and conversion of the plant components, such as reformer, CO_2 removal unit, boiler feed water treatment system, material handling systems for iron ore pellets and lump ore, were prepared and carried out. The existing shaft furnace was scrapped and replaced by two HYL moving reactors in a new reactor tower. Main new equipment incorporated consisted of two gas heaters, an additional CO_2 scrubber, and a compressor facility comprising two two-stage turbo-compressors for the reducing gas and two single-stage turbo-compressors for the cooling gas, all of them supplied by MAN-GHH.

Other new systems incorporated included the material handling, storage and screening systems for the DRI, as well as a control and instrumentation system, for which the control room was enlarged and redesigned.

The HYL PSSB plant was started up during the second half of 1993. Unfortunately, due to economic reasons the DRI production has been restricted. For the last four years, the HYL plant has been normally operating with one reduction unit only.

Figure 5. Perwaja Steel Sdn Bhd-HYL Direct Reduction Plant

LEBEDINSKY GOK, GUBKIN, RUSSIA, 1999

The Lebedinsky GOK HYL plant, located in Gubkin, Russia, has a production capacity of 900,000 ton/year of Hot Briquetted Iron (HBI).

The main design concepts of this plant are the following:

- Operation with Russian raw material from their local pelletizing plant, thus minimizing the HBI production costs. Iron ore pellets are transported by pipe conveyor from the pelletizing plant to the DR plant (1 km approximately).

- Provision of hot briquetting facilities for the production of 900,000 ton/year of highly metallized-Hot Briquetted Iron (HBI), using 4 briquetting lines, each consisting of screw feeder, briquetting press, string breaker and vibrating cooling conveyor.

- An electricity co-generation scheme, capable of generating most of the electricity requirements of the DR plant, leading to an external electricity consumption of only 25 kWh/ton HBI. The benefits of this configuration are reflected in lower operating costs and enhanced plant reliability.

The Lebedinsky GOK plant started up during the second semester of 1999, but experienced solids flow problems due to the very special raw material quality. The problems were carefully analyzed and solved after several months of unstable operation. The plant is currently working on a continuous basis, with an average plant productivity of 112% during the first semester of 2002. The plant set a production record in March, 2002, with 121% productivity and over 95% metallization.

Figure 6. Lebedisky GOK-HYL Direct Reduction Plant

OPTIMUM INTEGRATION OF DR PLANTS IN EXISTING STEEL MINI-MILLS

Ferrostaal/HYL have developed a new plant concept, which is named HYL Mini-Module (Figure 7), for the optimum integration of a direct reduction plant within an existing steel Mini-Mill. The following advantages are obtained:

- DRI is available on site, allowing steel production to be less dependent on conditions and fluctuations in the metallics market.

- Liquid steel quality is improved by the use of virgin iron units (DRI), enabling the Mini-Mill to meet the most stringent finished steel product specifications.

- DRI production is tailored to meet the requirements of each particular Mini-Mill. This new DR plant concept will typically operate with capacities of 300,000 to 500,000 ton/year of DRI.

- Investment costs for the HYL Mini-Module have been minimized in view of the following:

    - Small plant size.
    - Optimized plant design.
    - Compact layout.
    - Modular design.
    - Prefabricated equipment.
    - Shorter implementation time.
    - Use of existing infrastructure.

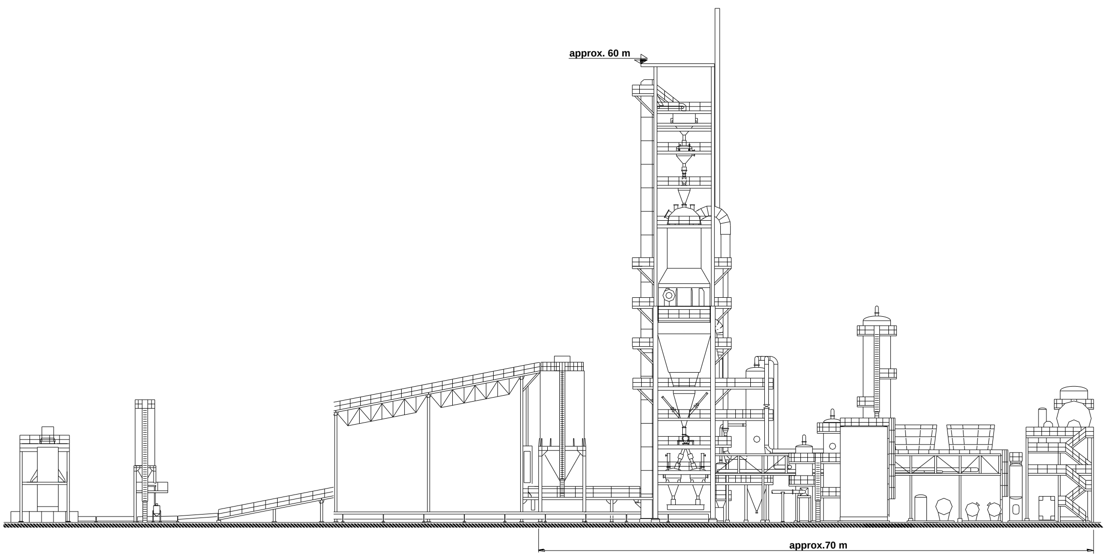

Figure 7. HYL Mini-Module

CONCLUSIONS

The successful operation of any industrial plant depends on many tangible factors and on some contingencies too. However, the most important factors are the technology maturity level, quality of equipment components, control of project management activities, plant building procedures, commissioning and start up activities, as well as the technology transfer process through conceptual engineering, personnel training, and technical assistance.

For the technology providers and general turnkey contractors, the learning process from former projects is vital to fine tuning both the technology and the critical plant components, as well as to optimize the plant operating practices. This is known as "Evolution", and it finally leads to reaching technology maturity and full plant reliability, where all expectations about proven technical solutions, plant investment, quality of equipment/supplies, project time-schedule, learning curve and operating cost parameters will be achieved with the minimum risk.

On the other hand, the searching for revolutionary technologies is an essential part of the basic human growth and it will never end. Like many other things in life, ***the challenge is to realize and understand the difference between Illusion and Truth...***