FASTMET®, FASTMELT®, and ITmk3®:
Development of New Coal-based Ironmaking Processes

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OVERVIEW

In recent years, world steel production has steadily increased. The current mainstream ironmaking technology is the blast furnace process that negatively impacts the environment. With global warming as a major consideration, concerns for decreasing the emission of carbon dioxide have increased accordingly.

With this as background, three new ironmaking processes, FASTMET, FASTMELT, and ITmk3, have been developed. These processes are based on the coupling reaction between the reduction of iron oxide and gasification of carbon, which can produce high quality iron units from iron ore fines and coal that exist in abundance all over the world. The energy consumption and environmental load of these processes are competitive compared with the large-capacity blast furnace process.

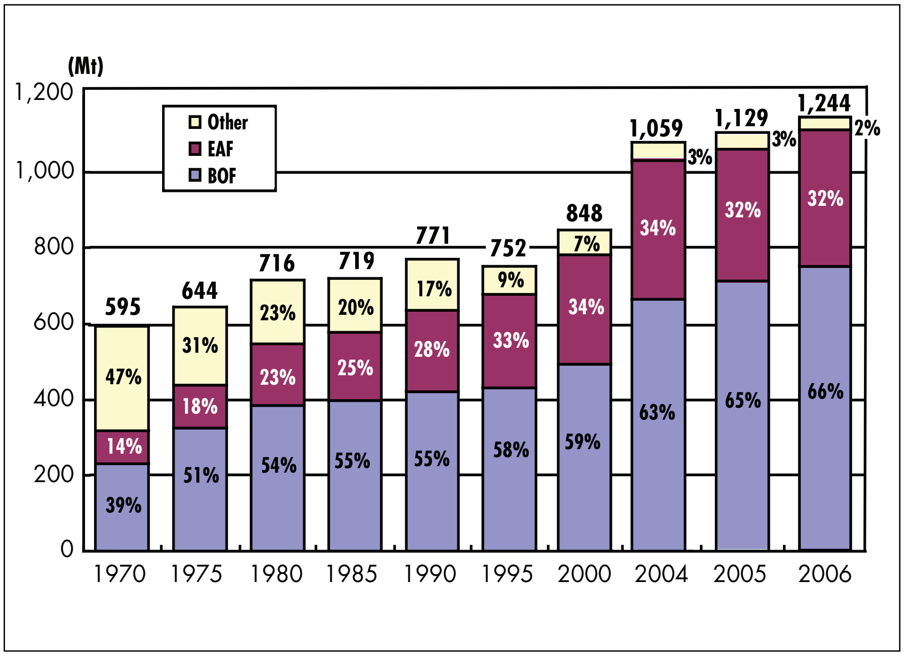

Figure 1 - Trend of world crude steel production

INTRODUCTION

World crude steel production has steadily increased, exceeding 1.2 billion tons in 2006, as shown in Figure 1.

The growth of steel production in Asian countries, including China, has been especially remarkable. One of the features in today's world steel industry is the increase in crude steel production from Electric Arc Furnace (EAF) steelmaking.

As steel production through the EAF route has grown over the years, the production volume of DRI has increased 70 times, from roughly 0.8 million tons in 1975 to approximately 60 million tons in 2006. (See Figure 2)

A major portion of the world's DRI and HBI is produced by gas-based processes, of which the MIDREX® DR Process had a 60%

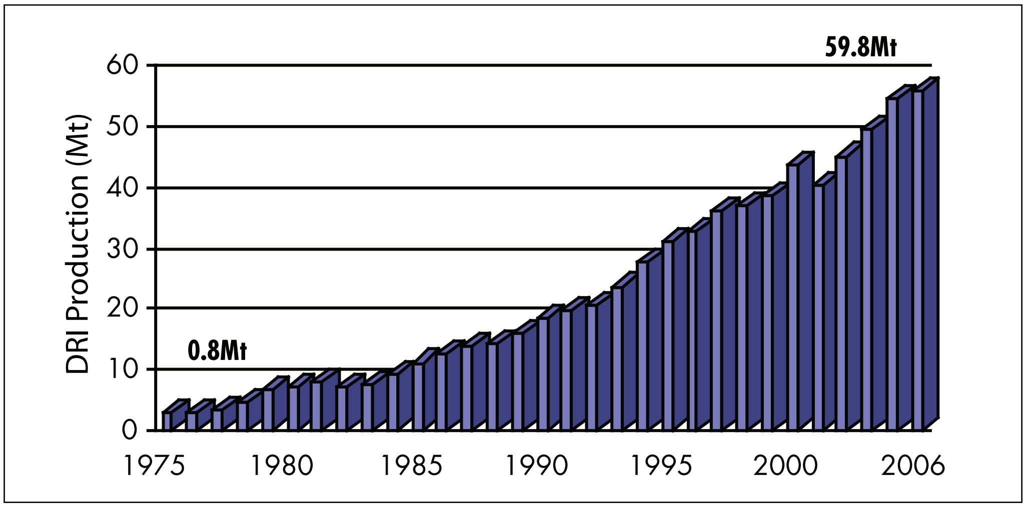

Figure 2 - World DRI production by year

share in 2006. (Figure 3)

Unfortunately, the locations of MIDREX Plants are limited to places where natural gas resources are abundant, since the plants use natural gas for iron reduction. In order to expand applications worldwide, it is necessary to develop reduced iron processes using coal, of which more abundant reserves are available in widespread geographic areas.

In response to this demand, three coal-based direct reduction ironmaking processes, FASTMET, FASTMELT, and ITmk3, have been developed. This paper explains why and how these coal-based DR processes will bring sustainable success to the steel industry.

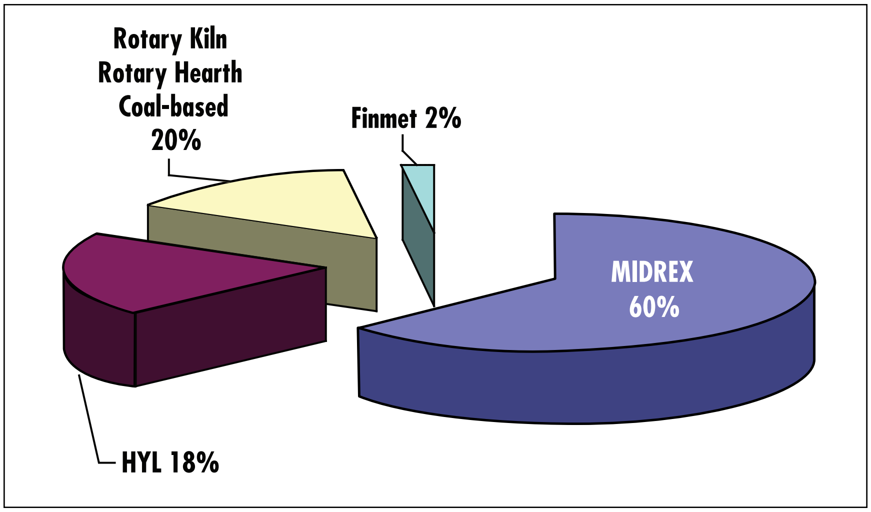

Figure 3 - World DRI production by process (2006)

COAL-BASED DIRECT REDUCTION PROCESSES

FASTMET Process

Figure 4 shows a schematic chart of reduction in a rotary hearth furnace (RHF). Iron ore and pulverized coal are mixed and agglomerated into pellets or briquettes. These agglomerates are fed into the RHF in one or two layers and heated rapidly to a maximum 1,350° C in the RHF by radiation heat. The oxides in the agglomerates are reduced to metallic iron by the composite carbon within the agglomerates. Recently, the reaction of composite pellets was investigated. The first reaction rate and relatively low starting temperature were reported due to the coupling reaction between reduction of iron oxide and gasification of carbon.

The DRI produced is continuously discharged from the RHF at a temperature of approximately 1,000° C and treated according to the customer's requirements.

Carbon monoxide generated from the agglomerates is used as a major fuel source in the RHF, and the fuel gas, which is equivalent to only 15% of the necessary energy, is added as a supplement. Thus, the FASTMET Process can attain a high-carbon utilization rate with reduced CO_2 emissions.

Kobe Steel and Midrex jointly began development of the FASTMET Process to establish this direct reduction technology. In 1995, the Kakogawa Demonstration Plant (KDP) with an annual capacity of approximately 20,000 tons was constructed to

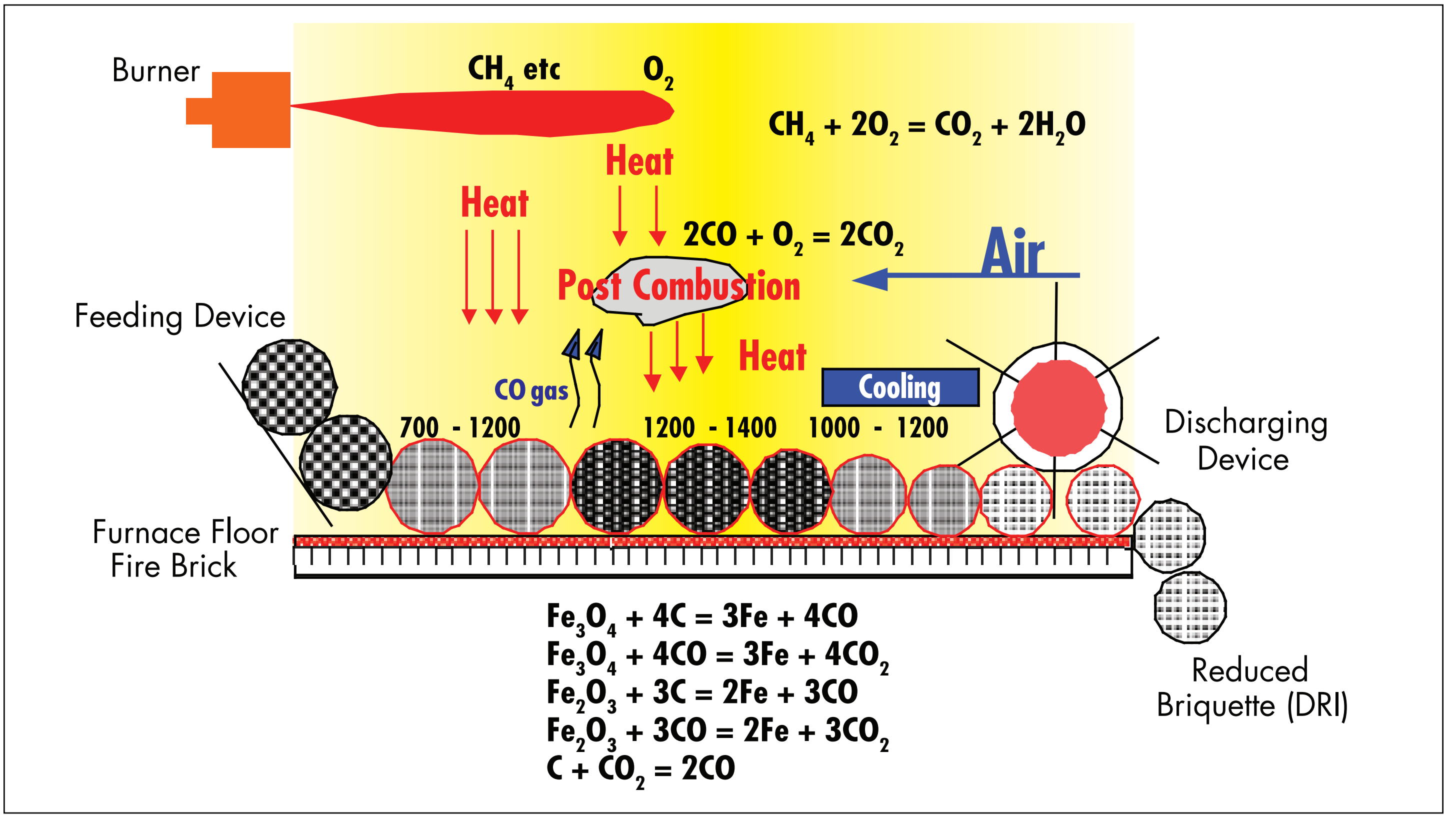

Figure 4 - Schematic drawing of reduction in RHF

demonstrate the process. Through this trial operation that continued until 1998, high metallic DRI and HBI were continuously produced at high productivity. The FASTMET Process proved to be a suitable process as a new ironmaking technology that utilizes coal as the reductant. The DRI or HBI produced can be charged into a melting furnace (EIF, EAF or SAF), BOF or Blast Furnace (BF). The benefits for BF include reducing the coke rate and increasing the hot metal production rate.

Plant Name	Capacity (t/y)	Operation Date
NIPPON STEEL Hirohata Works (No. 1)	190,000	April 2000
NIPPON STEEL Hirohata Works (No. 2)	190,000	February 2005
KOBE STEEL Kakogawa Works	16,000	April 2001

Table I - FASTMET® commercial plants

	Unit: Wt.%					
	Total Fe	Metallic Fe	FeO	C	S	Zn
Dry Ball	58.70	17.10	36.60	11.90	0.17	0.75
DRI	82.20	74.20	7.40	3.30	0.23	0.05

Table II - Chemical composition of Dry Ball and DRI

The FASTMET Process reduces iron ore at high temperatures above 1,300° C, evaporates heavy metals, such as zinc and lead in steel mill waste material, and thus produces DRI without heavy metals. The processing of steel mill waste material is an urgent issue in steelmaking facilities. In the FASTMET Process, the elements evaporated from the RHF are oxidized in the exhaust gas and collected as valuable crude zinc oxide.

Table I shows the plants that are in commercial operation. Three FASTMET commercial plants are currently recycling steel mill waste material.

Table II shows the chemical compositions of the dry ball pellets and DRI.

FASTMELT Process

Ash and sulfur contained in coal tend to migrate into the reduced iron. The FASTMELT Process (Figure 5) was developed to resolve this issue of migration. The process melts reduced iron, hot-transferred from the FASTMET Process, and separates it into molten iron and slag. At the same time, the molten iron is de-sulfurized. The gas discharged from the DRI melter

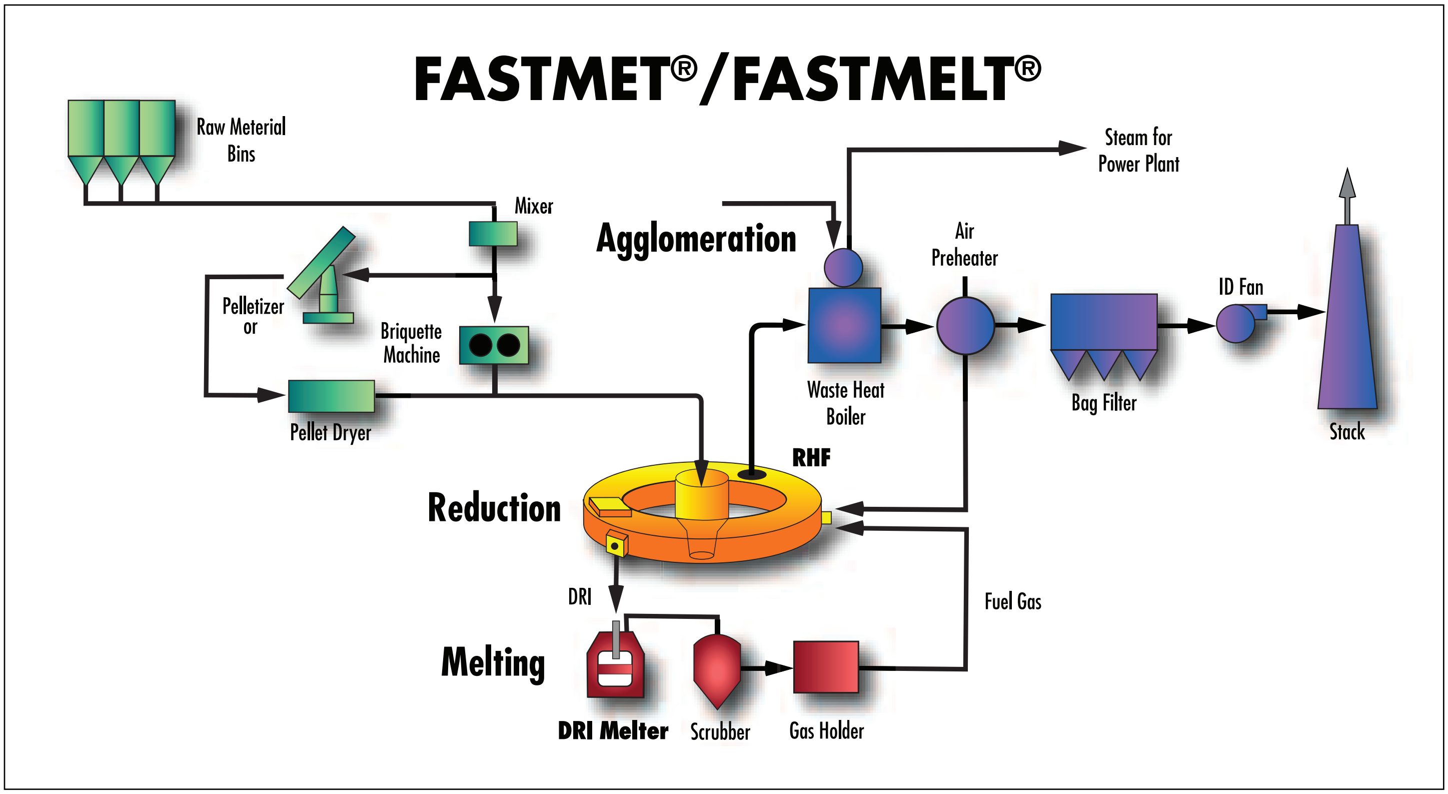

Figure 5 - FASTMELT® Process flow

consists mainly of CO and is used for the fuel gas in the RHF.

Either electricity or coal can be used as the energy source for melting. The choice of the energy source depends on conditions at the plant site. The use of coal as the energy source increases the amount of discharged gas and reduces the need for external fuel gas, such as natural gas.

The major design concept of FASTMELT is the achievement of high metallization DRI of over 90%. The DRI produced in the RHF is melted in the DRI melter to produce molten iron. It is important for the melting in the DRI melter to reduce the FeO contained in the DRI in order to prevent refractory damage in the DRI melter. Figure 6 shows the required energy for further reducing and melting in the DRI melter. High metallization of hot DRI reduces the thermal load in the DRI melter, as compared with that of cold ore; this protects the refractory.

The FASTMELT Process has been proven through melting campaigns at an EAF at Takasago Works, Kobe Steel, Ltd. in Japan, as well as in test operations of a small plant called a simulator at the Midrex Technical Center in the United States.

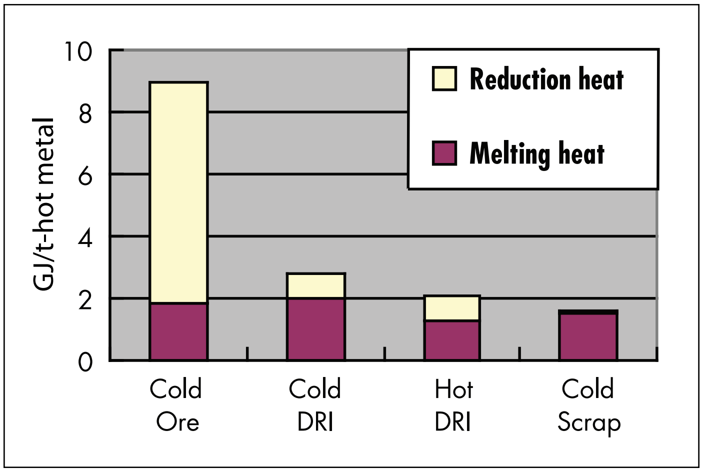

Figure 6 - Required energy for reducing and melting in the DRI melter

Temperature	Fe	C	Si	S	P
1,450 - 1,550° C	96 - 98%	2.0 - 4.0%	0.1 - 0.6%	<0.05%	<0.04%

Table III - Chemical analysis of FASTMELT® molten iron

Table III shows the typical chemical composition of FASTMELT hot metal. One standard FASTMELT commercial plant annually produces roughly 500,000 tons of molten iron.

ITmk3 Process

The ITmk3 Process, which also uses iron ore fines and pulverized coal, separates the iron nuggets and slag directly. We regard ITmk3 as a third generation ironmaking process; whereas, the current mainstream process of blast furnaces and converters is the first generation. The direct reduction processes, such as MIDREX®, are the second generation. The ITmk3 Process is based on a totally different concept from conventional processes.

The practical operation of the process proceeds as follows, and the process flow is shown in Figure 7.

1. Iron ore fines and pulverized coal are agglomerated into composite pellets.
2. Pellets are charged into an RHF, heated to 1,350-1,450° C, reduced, melted, and separated into iron and slag.
3. Molten iron is solidified into nuggets in the furnace, discharged after cooling, and separated from the slag.

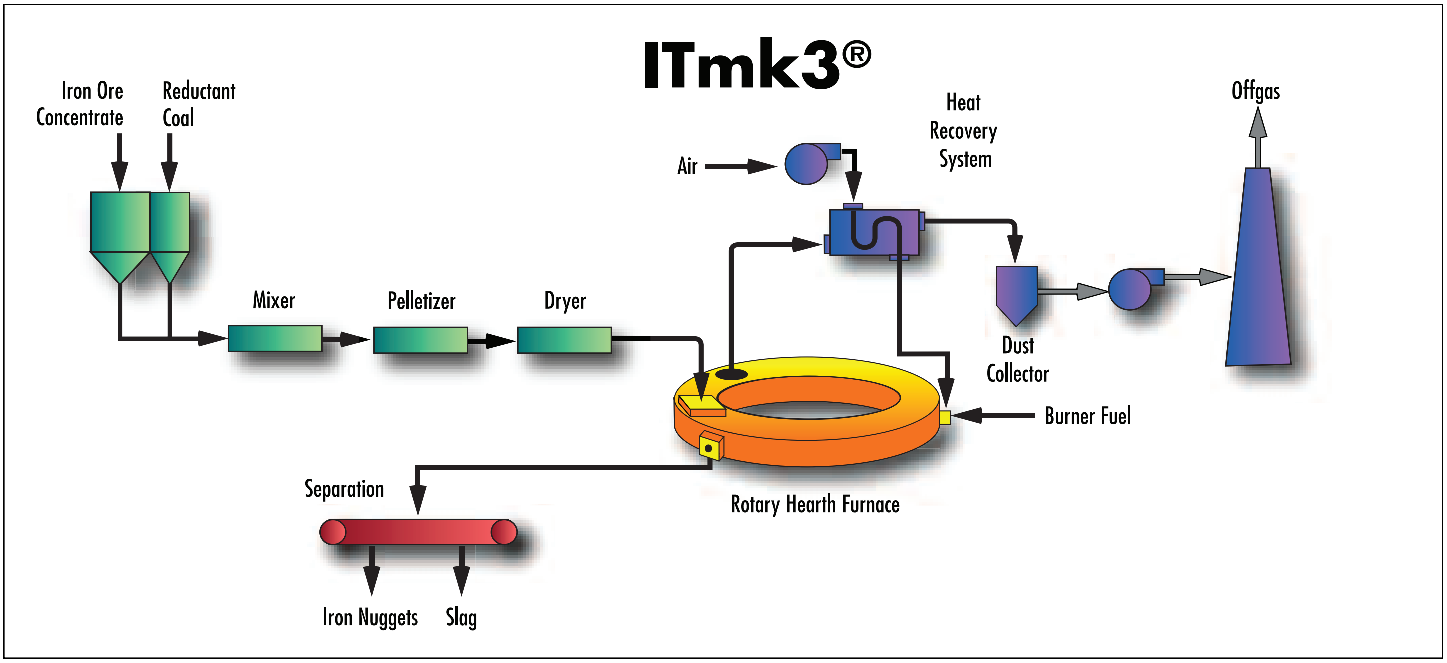

Figure 7 - ITmk3® Process flow

In the RHF, the following reactions take place when the carbon composite pellet is heated:

$$Fe_xO_y + yCO = xFe + yCO_2 \quad (1)$$

$$CO_2 + C = 2CO \quad (2)$$

$$C(s) = C(carburized) \quad (3)$$

$$Fe(s) = Fe(l) \quad (4)$$

The series of reactions are completed in approximately 10 minutes. Figure 8 shows both the outside and inside views of the agglomerate during reduction and melting in a laboratory furnace.

The ITmk3 Process enables the use of various raw materials, including non-coking coal and low-grade ore, without using expensive coke. The process is simple, as well as environmentally friendly. Table IV shows the iron ore grades and coal grades that can be used by ITmk3. A typical appearance of the iron nuggets and their composition quality is shown in Figure 9.

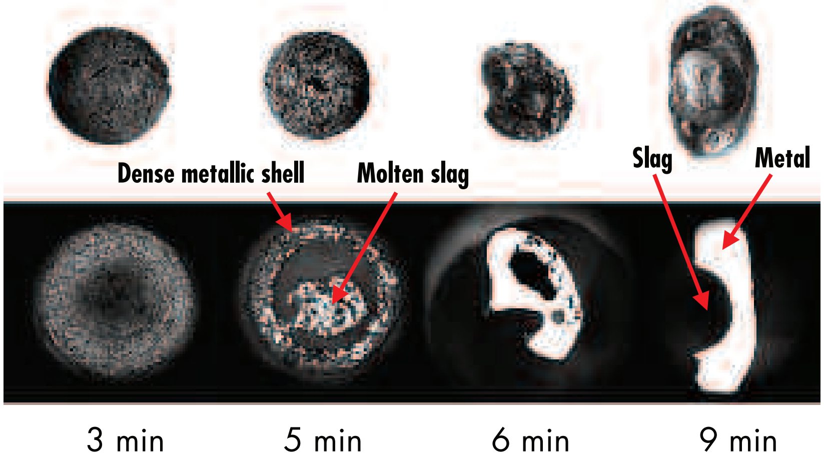

Figure 8 - Product figure and cross-sectional view of time sampled pellets

	Applicable	Preferable
Iron Ore (Wt.%)	TFe > 56% SiO_2 < 6%	TFe > 60% SiO_2 < 5%
Coal (Dry-base Wt.%)	FC > 50% VM < 45% Ash/FC < 25%	VM < 30% S/FC < 0.9%

Table IV - Required grade of iron ore and coal for ITmk3®

Item	Content (%)
Metallic Fe	96 – 97
C	2.5 – 3.0
P	0.01
S	0.05 – 0.07

Figure 9 - Photo and chemical analysis of iron nuggets

Figure 10 - ITmk3® Pilot Plant at Kakogawa Works

We started development of the ITmk3 Process in 1996, built a pilot plant at our Kakogawa Works (see Figure 10) to prove the process concept, constructed a demonstration plant with an annual capacity of 25,000 tons in the United States, and completed trials in 2004. Plans for commercial plants of 500,000 tons annual capacity are now under consideration.

Performance of New Ironmaking Technologies

Kobe Steel performed a study of processes to produce metallic iron from raw materials. The RHF Processes and the conventional Blast Furnace Process were evaluated to compare their energy consumptions and CO_2 emissions.

On the following page, Figure 11 shows the energy balance of the FASTMELT Process. The gas generated from the Electric Ironmaking Furnace® (EIF) is used as fuel for the RHF. The sensible heat from the RHF exhaust gas is recovered as steam and used for power generation.

Also on the following page, Figure 12 shows the energy balance of the ITmk3 Process, a process that can produce pure metallic iron with only an RHF. By-products are not generated by the RHF. The sensible heat from the RHF exhaust gas can be recovered, the same as in the FASTMELT Process.

The energy consumptions and CO_2 emissions in the FASTMELT and ITmk3 Processes are lower than in the blast furnace process, as

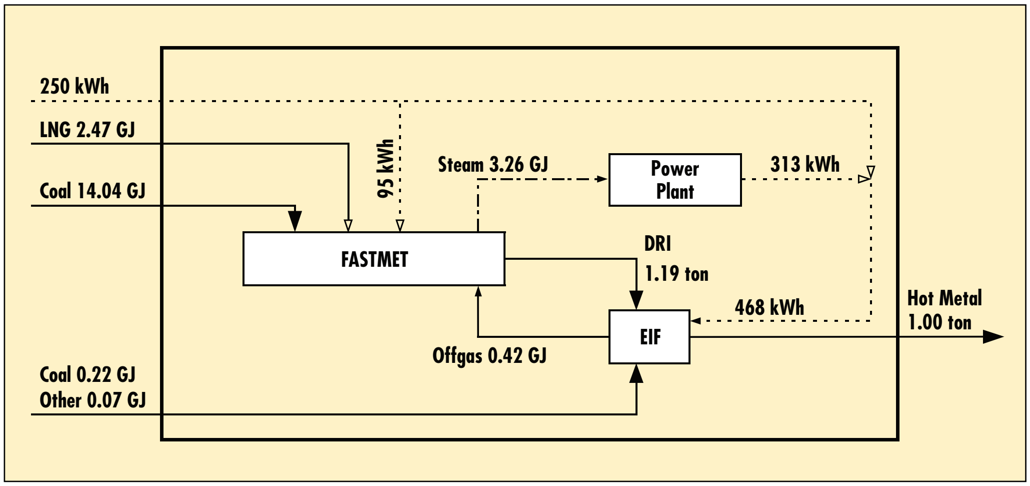

Figure 11 - Energy balance of FASTMELT® (500,000 t/y)

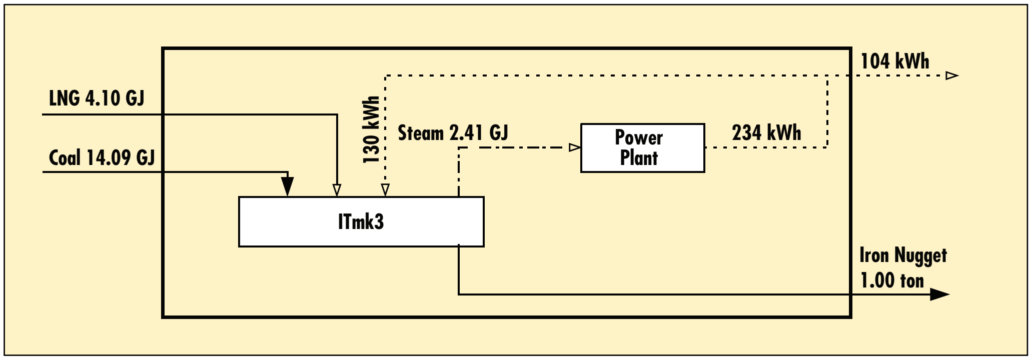

Figure 12 - Energy balance of ITmk3® (500,000 t/y)

shown in Figure 13 and Figure 14. This is due to the high efficiency of coal utilization in the two processes.

It should be noted that ITmk3 iron nuggets are not hot molten iron; they are cold solid iron. Additional energy is required to melt iron nuggets in a steel converter.

Therefore, FASTMELT, which can supply hot molten iron, is more suitable than ITmk3 in locations close to where the iron product is consumed.

In contrast, ITmk3 is advantageous if constructed at a mining site. Iron nuggets are easy to transport because they are pure metallic solid iron and difficult to re-oxidize. Transportation energy and CO_2 emissions can be reduced by transporting iron nuggets from the mining site to consuming locations, because the weight of the iron nuggets is one-half and the volume is one-tenth, compared with iron ore and coal.

CONCLUSION

The FASTMET, FASTMELT, and ITmk3 Processes suffer considerably less from raw material restrictions and are superior to the Blast Furnace in energy efficiency. With growing concerns about the conservation of resources and the environment, the processes are receiving more and more attention. We will continue to develop and supply coal-based direct reduction ironmaking processes and plants. In doing so, our goal is to contribute to growing the ironmaking industry, as well as improving the global environment.

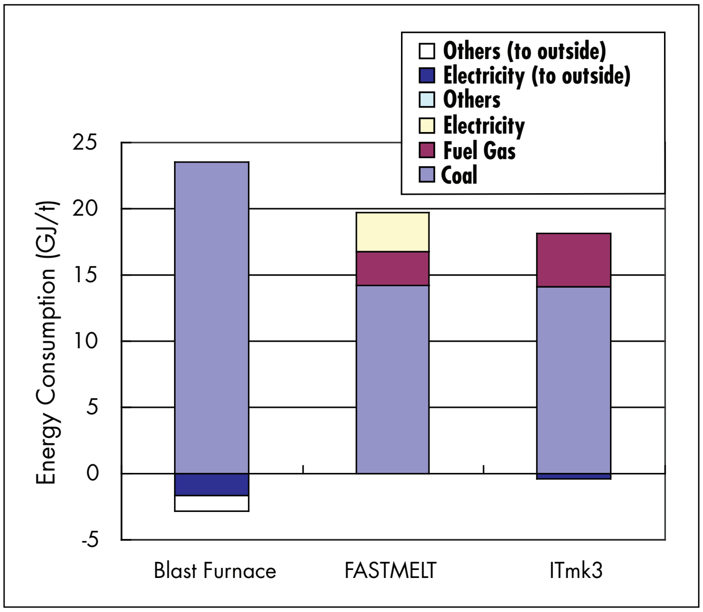

Figure 13 - Energy consumption of ironmaking processes

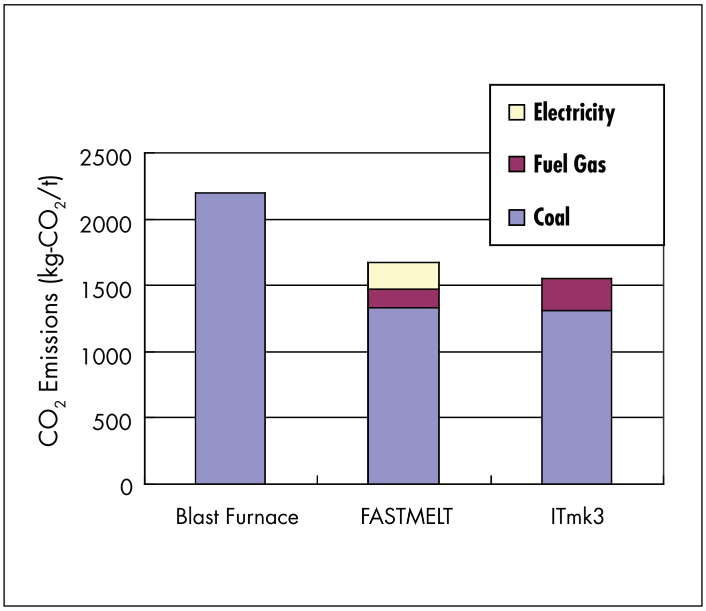

Figure 14 - CO_2 emissions of ironmaking processes