

**DIRECT FROM MIDREX**

**From The Hearth:**

# **RHF** **Technologies**

**SPECIAL REPORT WINTER 2008/2009**

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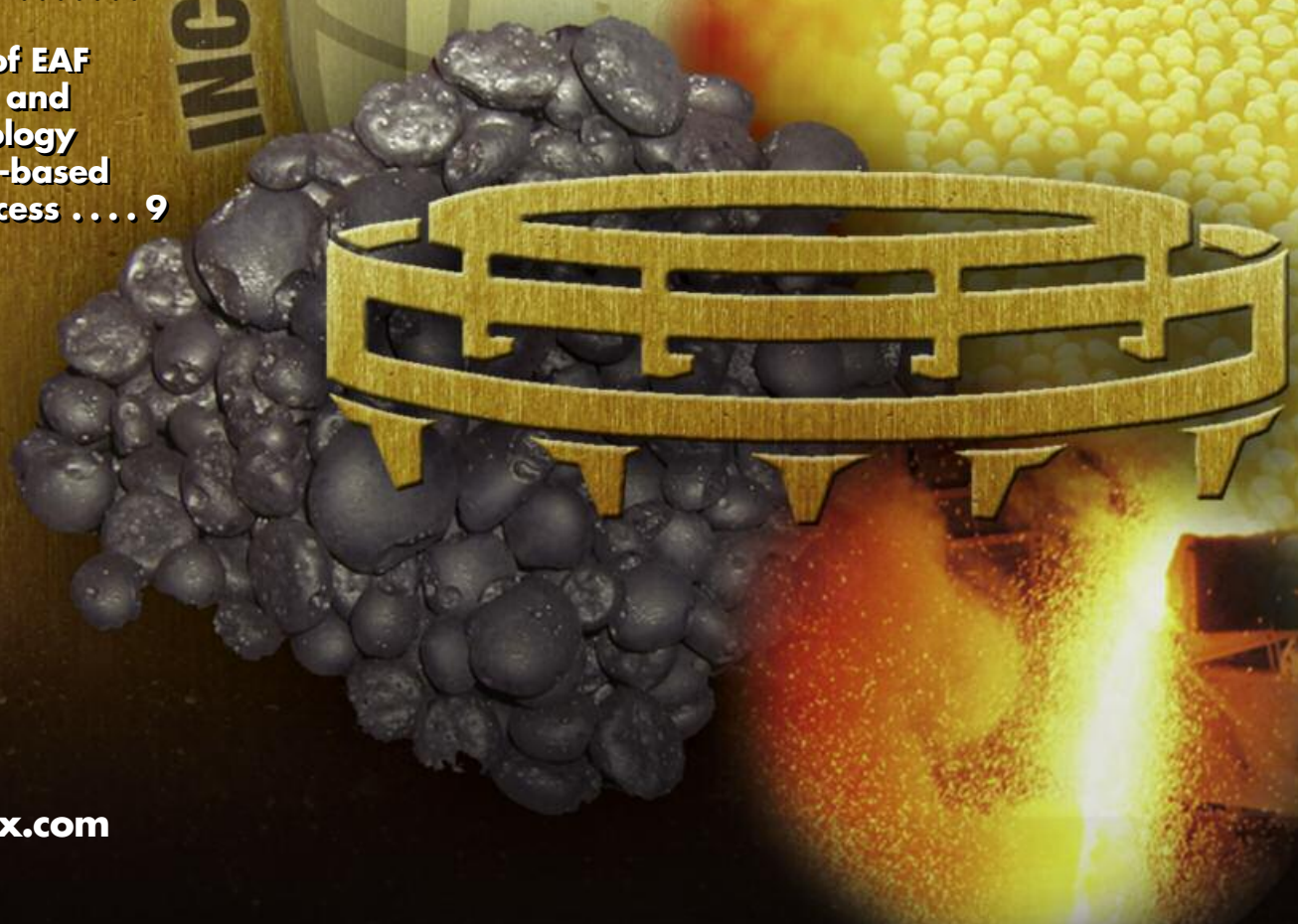
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**INC. • MIDREX TECHNOLOGIES, INC.**



## Commentary

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### Innovation via Continuous Technology Development

The roots of the success that MIDREX® enjoys today (each year since 1987, MIDREX Plants have produced approximately 60 percent of the world's DRI) can be traced back to the 1920s with the founding of the Surface Combustion Company in Toledo, Ohio. Surface Combustion was a leader in thermal processing of minerals, and in the 1940s and 1950s sold 41 shaft furnaces for indurating iron oxide pellets. In 1959, Midland-Ross Corporation acquired Surface Combustion, and operated it as a separate division. It was there that Donald Beggs, Manager of the Surface Combustion Division's Research Group, conceived of the idea of combining stoichiometric natural gas reforming with the shaft furnace direct reduction of iron ore (the MIDREX® Process).

During the early 1960s the Surface Combustion Division first developed the Heat Fast process for reducing iron ore using coal in a rotary hearth furnace (RHF). A two million dollar demonstration plant was built in Cooley, Minnesota and 9,000 tons of DRI were produced and tested in an experimental blast furnace. While technically successful, the economics were not feasible and further work on Heat Fast was suspended, while development of the shaft furnace technology continued unabated.

In 1983 Kobe Steel Ltd. (KSL) purchased Midrex, which had previously relocated to Charlotte, North Carolina. KSL revived interest in the coal-based RHF technologies, renaming the process FASTMET®, and constructing a 2.7 meter diameter rotary hearth furnace (process simulator) at the Midrex Technical Center in Charlotte. Over 100 campaigns were

conducted from 1992-1994, and these successes provided the justification for KSL to construct an 8.5 meter diameter demonstration plant at their Kakogawa Works in Japan. This demonstration plant started up in 1995 and was the world's first rotary hearth direct reduction plant to make highly metallized DRI.

The first commercial FASTMET facility was constructed at Nippon Steel's Hirohata Works in 2000. This plant processes 190,000 tons per year (tpy) of integrated steel mill waste and produces DRI that is fed to a BOF for melting. In 2001, KSL constructed a 14,000 tpy commercial FASTMET Plant at its Kakogawa Works, processing integrated mill and EAF dusts, producing DRI and recovering zinc oxide. These installations were followed by a second Nippon Steel Hirohata



plant in 2005 and a third Hirohata plant that started up in late 2008 (both plants are also rated at 190,000 tpy). A fourth Hirohata plant, this one rated at 400,000 tpy, has recently been announced.

In 1996 KSL began experimenting with melting FASTMET-type feed pellets (pellets containing iron ore and coal). A unique phenomenon was discovered, namely that if the temperature was raised to about 1450° C after reducing the iron ore, the pellet melted and the molten iron and slag separated, resulting in a nugget of nearly pure iron, plus carbon. This process was named "ITmk3" for "Ironmaking Technology mark 3", with Mark 1 being blast furnace ironmaking and Mark 2 being the natural gas-based direct reduction process (the MIDREX Process).

*(Commentary continued on next page)*

## Commentary

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An ITmk3 Pilot Demonstration Plant was built in Silver Bay, Minnesota through a partnership with the State of Minnesota, Kobe Steel, Cleveland-Cliffs (now Cliffs Natural Resources), Ferrometals and Steel Dynamics. The 25,000 tpy plant was named "Mesabi Nugget" and started up in 2003. Based on the successful operation of this demonstration plant, Kobe Steel and Steel Dynamics formed a joint venture (JV) to build the world's first commercial ITmk3 plant in Hoyt Lakes, Minnesota. The plant is scheduled for start-up in the third quarter of 2009. Kobe Steel and Cliffs Natural Resources have also formed a JV and are working towards constructing the second commercial ITmk3 plant. ITmk3 promises to be a revolutionary process, enabling production of a premium grade iron product without the use of coke.

Consistent research and development efforts have been a hallmark of Midrex since the company's inception. It can take many years, and in some cases decades, to develop new technologies and to successfully commercialize them. Our Research and Development Technology Center is the heart of this effort, with the RHF Process Simulator a key component for our coal-based reduction processes. We continue with our technology development programs throughout the boom and bust cycles of the steel industry, realizing that it is essential to develop new technologies to position the company for the growth opportunities that present themselves during the inevitable economic recoveries.

These are certainly extraordinary times for the steel industry, and for the global economy in total. The speed and the magnitude of this economic downturn is unprecedented. The quick reaction by the steel industry to dramatically cut steel production in order to adapt to decreasing demand will help insure a more rapid recovery.

No one is sure when the recovery will begin, but Midrex will continue to innovate via our technological development efforts and we remain optimistic knowing that the long term demand for steel is strong and that our industry has a bright future.



*Larry Shields  
Plant Sales Manager*

### MISSION STATEMENT

*Midrex Technologies, Inc. will be a leader in design and integration of solids and gas processes. We will meet or exceed performance expectations, execute projects on time, enhance existing product lines, and provide value-added design, procurement, logistics and field services to our clients. We will develop new business opportunities that will challenge our employees and maintain the economic vitality of our company. Our employees are the key to our success, and we are committed to encouraging them to grow professionally and personally.*

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# Changes in Paradigm: ITmk3® and FASTMELT® Applications for Southeast Asia



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*Editor's note: this article was adapted from a paper presented at the SEAISI Conference in May 2008*

## INTRODUCTION

To satisfy the region's growing demand for steel, mini-mills and rolling mills have been successfully developed in Southeast Asia. They use mostly imported raw materials, namely, scrap/pig iron and semi-finished products to achieve their missions. Recently, however, they have been seriously affected by the scarcity and drastic price increases of these raw materials. In order to satisfy demand for steel and to supply appropriate products to the market, some companies are trying to secure stable iron units through the installation of mini or small blast furnaces. Moreover, construction of conventional integrated iron and steel complexes, including large blast furnaces, is also planned in Thailand, Malaysia and Vietnam.

Under present market circumstances, the mini/small blast furnace route and the traditional integrated method may not be the best options for all Southeast Asian countries. Rotary hearth furnace (RHF)-based technologies, such as ITmk3® and FASTMELT®, are noteworthy processes which may be the best solutions when considering a country's indigenous resources. Adopting the RHF-based technologies rather than the mini/small blast furnace or large blast furnace may be the best approach for sustainable development.

## THE INTEGRATED IRON AND STEEL COMPLEX

It is estimated that more than 800 blast furnaces exist in the world and they produce more than 65 percent of crude steel. No process is said to be superior to the blast furnace in terms of energy efficiency and productivity, but it should be noted that these efficiencies can be obtained only in very large blast furnaces.

Methods for the development of the iron and steel industry show that the basic concept comes from economies of scale. Simultaneously, the quality control to produce high quality products on time in accordance with the requests of customers

has been a focus of blast furnace progress. Development of immense iron ore mines with huge transportation capacity supported by the appropriate infrastructure enables mass production in the integrated iron and steel complex applying the blast furnace route. This method predominates in Japan, since the country needs to import almost all ironmaking raw materials. In order to reduce unit production costs, the mass production method has been adopted and the volume of blast furnaces has been increased continually. Among the 28 existing blast furnaces in Japan, eight have volumes more than 5,000 m<sup>3</sup>, and the average volume is approximately 4,000 m<sup>3</sup>. The largest furnace, of 5,775 m<sup>3</sup>, is at Nippon Steel Oita Works. Through continued improvement and adoption of new technologies, efficiency has been realized in these integrated iron and steel complexes. The other distinctive features are long term supply contracts for raw materials and location along the coast to reduce transportation cost.

Recently, certain steel companies in China have commenced construction of large scale integrated iron and steel complexes. Korean steel companies are planning to install more blast furnaces and subsequently, certain companies in Malaysia and in Thailand are pursuing the same route. Considering the economies of scale paradigm, construction of an integrated iron and steel complex is one of the methods to develop an iron and steel industry. There are, however, some disadvantages to the blast furnace route:

## Raw Materials

Iron ore and coke are the major raw material inputs to the blast furnace. Three major mining companies, namely Vale, BHP Billiton and Rio Tinto, account for 79 percent of the international iron ore trade. Therefore, if domestic ore is not available, it is almost inevitable that iron ore must be procured from these companies. On the other hand, the market price for iron ore increased 65-100 percent in 2008 and the price trend for the last few years was strongly upward. Because of Chinese demand, blast furnace operators may face not only price increases, but also a scarcity of supply. China export coke prices increased to \$700/t, in mid-2008, though the average price in 2007 was approximately \$200/t. Due to the scarcity of coking coal and coke in the

international market, project developers must work hard to secure their coke needs. If the situation becomes more serious than today, development of an integrated mill will be very difficult.

### Capital Cost

The construction of an integrated iron and steel complex requires a huge budget. The complex usually consists of a blast furnace, coke ovens, sintering plant, basic oxygen furnace (BOF), caster and rolling mills. In addition, sufficient supporting facilities, such as roads, port, power station and water treatment system, need to be built. Generally it is said that it costs \$1.5 billion for the production of three million tons of molten iron. However, in some cases the cost may be \$2 billion or more. In certain cases, the investment cost for infrastructure and utilities other than the main production facilities may account for more than 70 percent of the total investment cost when the complex is built on a greenfield basis. Scope of work including the supporting facilities shall be properly evaluated.

### Project Development Time and Construction Period

To be successful, all the conditions described above should be scheduled and planned correctly. Since the project entails infrastructure and utilities, it takes significant time for planning and construction. Normally, it requires several years merely for the planning stage and then additional years to complete the construction. If the iron ore mine is included in the project scope, assessment, development and actual mining will also extend the lead time. All of the lead time may need to be considered as an opportunity loss compared with faster project materialization by applying other new technologies.

### Operations and Quality Control

Generally, an integrated iron and steel complex is established to produce high quality products, such as flat products for the automobile industry. However, it is not possible to obtain high quality products by simply installing the production facilities described above. Good layout of the complex, a detailed production control system that covers the quality and production structure of the complex and on-time supply chain management are required. Experienced employees incorporated in a well-designed organization are needed to achieve all of these.

Construction of an integrated iron and steel complex may be a good solution for supplying steel products to a country; however, the huge investment cost, long lead time and difficulties in procuring raw materials should be thoroughly evaluated.

### MINI/SMALL BLAST FURNACE

Many mini-mills in Southeast Asian countries are planning to introduce mini or small blast furnaces. Because mini-mills in the region are facing cost increases and scarce raw materials, namely scrap and pig iron, they are seeking alternate feedstock. One solution is to use hot metal in the electric arc furnace (EAF). The installation cost of a mini/small blast furnace is much less than a conventional integrated complex. Small blast furnaces are defined as having volumes less than 1,000 m<sup>3</sup> and a mini-blast furnace is less than 300 m<sup>3</sup>. Though more than 3,000 mini-blast furnaces are

said to have been installed in China in 2006, the country banned both the operation of mini-blast furnaces less than 300 m<sup>3</sup> and the construction of small blast furnaces

Unfortunately, these bans caused changes in the supply of mini/small blast furnaces in Southeast Asia. The Chinese engineering companies that supplied blast furnaces in China shifted their market from the domestic to the Southeast Asian region. It seems the low initial investment cost of mini/small blast furnaces meets the requirements of mini-mills in the region, and there are many installation plans in the works. On the other hand, the attractive initial investment is not a solution for steel manufacturers in developed countries. Following are disadvantages of mini/small blast furnaces:

### Uncertain Capital Cost

The cost of a small blast furnace of volume 500 m<sup>3</sup>, which produces approximately 500,000 tons annually, is said to be \$50 million, with a construction period of 12 months. The price seems to include a sinter plant but excludes coke ovens and environmental protection equipment. It also does not include necessary infrastructure.

### Iron Ore

The mini-blast furnace can utilize lower grade iron ore compared with the blast furnace. Since the volume purchased, however, is far less than that of an integrated complex, the mini/small blast furnace may suffer from inferior purchasing conditions.

### Coke

About 0.6 tons of coke are consumed in the production of one ton of hot metal by a 500 m<sup>3</sup> blast furnace. Though mini-blast furnaces can utilize lower grade coke compared with the large blast furnace, unit consumption efficiency is worse. Furthermore, pricing difficulties are predicted and, as with iron ore, the smaller volume purchased does not provide for advantageous leverage in procurement.

### Environmental Compatibility

Though environmental friendliness is one of the most important concerns of the iron and steel industry, it appears that many of the mini/small blast furnace projects in the Asian region are not designed to control emissions properly. Additionally, countermeasures must be taken for de-NO<sub>x</sub> and de-SO<sub>x</sub>. Because of the high coke rate, CO<sub>2</sub> emissions from a mini/small blast furnace are higher than other processes.

### BASIC CONCEPT OF RHF-BASED TECHNOLOGIES

As explained in the introduction, ironmaking facilities are required in Southeast Asia to secure stable raw materials supplies. The ITmk3 and FASTMELT Processes are noteworthy RHF technologies that provide good solutions to those steel manufacturers who need pig iron or hot metal. The processes have simple operation, economical investment costs, environmental compatibility and a shorter lead time for project materialization. FASTMELT provides a source of high quality

Steelmaking Application/Process	Feedstock	Reductant	Product	Steelmaking Vessel	Location
ITmk3®	Iron ore fines	Non-coking Coal	Iron Nuggets	EAF	Mine site or central
FASTMET®	BF/BOF/EAF dust Iron ore fines	Non-coking Coal	DRI	EAF BOF	Steel mill or central
FASTMELT®	Iron ore fines BF/BOF/EAF dust	Non-coking Coal	Hot Metal	EAF BOF	Steel mill or central
Blast Furnace	Iron oxide sinter and pellets	Coke	Hot Metal	BOF	Coastal works
MIDREX® Process	Iron oxide pellets	Natural Gas	DRI/HBI	EAF	Gas-rich area

Table I - Ironmaking Process Comparison

hot metal for the developing iron and steel industry. Moreover, the plant can be built in stages in accordance with the demand forecast. The KSL RHF-based processes may provide the best solutions for the sustainable development of the Southeast Asian iron and steel industry.

### Features

For detailed technical descriptions of ITmk3 and FASTMELT, see the Winter 2007/2008 edition of *In the Round*. The commercial scale of both ITmk3 and FASTMELT Processes is 500,000 tons of product per annum. The raw materials are iron ore fines and non-coking coal. Though it depends on the quality of iron ore and coal, approximately 750,000 tons of iron ore and 250,000 tons of non-coking coal will be used as raw materials. Table I shows the characteristics of the RHF processes compared with other iron-making methods.

ITmk3 produces a pig iron-grade nugget, a premium quality feedstock for EAF use. It also is an ideal way for iron ore mining companies to process either magnetite or hematite for the production of iron nuggets. Plants can be located at mine sites, ports or in steelmaking facilities.

FASTMELT produces high quality, blast furnace-grade hot metal for EAF and/or BOF use, which is an alternative to the mini/small blast furnace. Plants can be located adjacent to an EAF or BOF in steelmaking facilities for efficient use of hot metal.

### Utilization of Low Grade Iron Ore

Because pellet feed cannot be used for sintering, normally a pellet plant must be installed for utilization of very fine ores. Beneficiated pellet feed with a particle size under 44 microns can be used in RHF-based processes, since they include mixing and agglomeration steps. Thus, an RHF process may be used to extend iron ore mine life without the need for a pellet plant and only require the installation of a beneficiation plant. ITmk3 Plants in the United States may be installed to utilize low grade iron ore with less than 30 percent iron content. Formerly, this material was beneficiated to produce pellet feed. Utilization of these iron ore

fines without installation of a several-million-ton capacity pellet plant can provide an advantage for mining companies.

### COMPARISON OF ITmk3 AND MINI/SMALL BLAST FURNACES

It is obvious that one of the most important concerns for the investor in an ironmaking project is project feasibility. In addition to the market outlook, competing technologies must be compared and the economics confirmed. As operating data for mini/small blast furnaces is not easily available, the following analysis utilizes data collected from various industry sources.

### Basis of Analysis

Costs of all iron and steelmaking raw materials and selling prices of products skyrocketed from mid-2007 to mid-2008, then plummeted in late-2008. The analysis in this section uses expected long-term average prices as shown in Table II.

The assumed iron ore and coke costs and pig iron price are essentially the same as early 2007. Since coke is one of the most important raw materials for blast furnaces, two cost scenarios are applied in this study for comparison purposes. For both the ITmk3 Plant and mini/small blast furnace, the annual production volume is 500,000 t. The assumed plant costs are \$200 million for ITmk3 and \$100 million for the mini/small blast furnace, both of which include supporting facilities, such as utilities and infrastructure, for

Input Costs	
Iron Ore – Imported from Brazil	\$50
Coal - Vietnam	\$35
Coke – Imported Scenario 1	\$180
Coke – Imported Scenario 2	\$300
Selling Price	
Pig Iron	\$450

Table II - Assumed Costs and Prices (per ton)

	Unit Cost	ITmk3		FASTMELT		Small BF	
		Unit Consumption	Production Cost	Unit Consumption	Production Cost	Unit Consumption	Production Cost
	US\$/Unit	Unit/t Nuggets	Unit/t Nuggets	US\$/thm	US\$/thm	US\$/thm	US\$/thm
<b>1. Variable Cost</b>							
1) Iron Ore	50	1.5	75.00	1.5	75.00	0.5	25.00
2) Sinter*	57					1.3	74.10
3) Pellet							
4) Coal	35	0.5	17.50	0.42	14.70		
5) Coke 1	180					0.61	109.80
6) Coke 2	300					0.61	183.00
7) Electricity	0.06	150	9.00	750	45.00	136	8.16
8) Fuel	10	4.6	46.00	2.5	25.00		8.50
9) Consumables			13.00		20.00		6.20
10) Utilities			1.40		1.60		14.90
Subtotal: Coke 1			161.90		181.30		246.66
Subtotal: Coke 2							319.86
<b>2. Fixed Coast</b>							
1) Labor			2.00		2.00		2.00
2) Maintenance			5.00		5.00		3.00
3) Others			12.00		12.00		13.20
Subtotal			19.00		19.00		18.20
Grand Total: Coke 1			180.90		200.30		264.86
Grand Total: Coke 2							338.06

Table III - Production Cost Comparison

\*Sinter: Iron Ore Price plus US\$ 7 for processing

a standalone plant.

Table III shows the unit production costs together with the unit consumptions and the unit costs given in Table II. Transportation cost is not considered in this study, as it is a variable depending on the location of the project.

### Comparison of Cash Generation

By utilizing the production costs calculated in Table III, the annual turnover and cash from the operating activities are estimated for ITmk3 and the small blast furnace in Table IV. The economics for FASTMELT can be calculated in the same manner.

	Unit	ITmk3	Small BF 1	Small BF 2
<b>1. Production Cost</b>	US\$/t	180.90	264.86	338.06
<b>(coke cost)</b>	US\$/t		180	300
<b>2. Annual Production</b>	t	500,000	500,000	500,000
<b>3. Annual Production Cost</b>	US\$/y	90,450,000	132,431,400	169,031,400
<b>4. Product Sales Price</b>	US\$/t	450	450	450
<b>5. Turnover</b>	US\$/y	225,000,000	225,000,000	225,000,000
<b>6. Cash: Operating Activities</b>	US\$/y	134,550,000	92,568,600	55,968,600

Table IV - Cash from Operating Activities

A comparison of ten years cumulative cash flow between ITmk3 and the small blast furnace is shown in Figure 1. The difference in cumulative cash flow between the two processes, as shown in Figure 1, is \$419.2 million, assuming a coke cost of \$180/t and \$785.8 million for \$300/t coke.

Although the initial investment cost of ITmk3 is double that of the small blast furnace, the selection of an ironmaking process should be considered from the long-term aspects, including sustainability, since the production facilities are operated and maintained for more than 20 years.

**Environmental Compatibility**

As shown in Figure 2, ITmk3 reduces CO<sub>2</sub> emissions by approximately 400 kg/t iron compared to the small blast furnace. The numbers assume no heat recovery.

As the CO<sub>2</sub> figure is calculated for a blast furnace of 500 m<sup>3</sup> volume, it is probably higher for mini-blast furnaces less than 300 m<sup>3</sup>. Also, as the operational conditions are different for each mini/small blast furnace, accordingly the volume of CO<sub>2</sub> emissions must be calculated for each location.

If mini/small blast furnaces exist or if conditions allow them to be built, there is a good possibility for the clean development mechanism (CDM) to be approved by the United Nations when an RHF-based process is installed. This enables monetization of CO<sub>2</sub> credits. Though the market price for one ton of CO<sub>2</sub> will be assessed in each case, a value of \$20/ton can be expected judging from the present CDM market situation in Asia. Thus, if a 500,000 tons per annum ITmk3 plant were to be built instead of a mini-blast furnace, the project could generate \$4,000,000 per year by selling the CO<sub>2</sub> credits on the market.

As no data for NO<sub>x</sub>, SO<sub>x</sub> and PM10 emissions were obtained for the mini/small blast furnace, it is not possible to make a direct comparison among the processes. However, considering the present operational conditions of the mini/small blast furnace in Asia, the RHF-based technologies are expected to drastically reduce these emissions.

**CONCLUSION**

Raw material prices, such as iron ore, scrap and pig iron, have drastically increased for the last several years. As steel manufacturers in the Southeast Asian region face difficulties in procuring raw

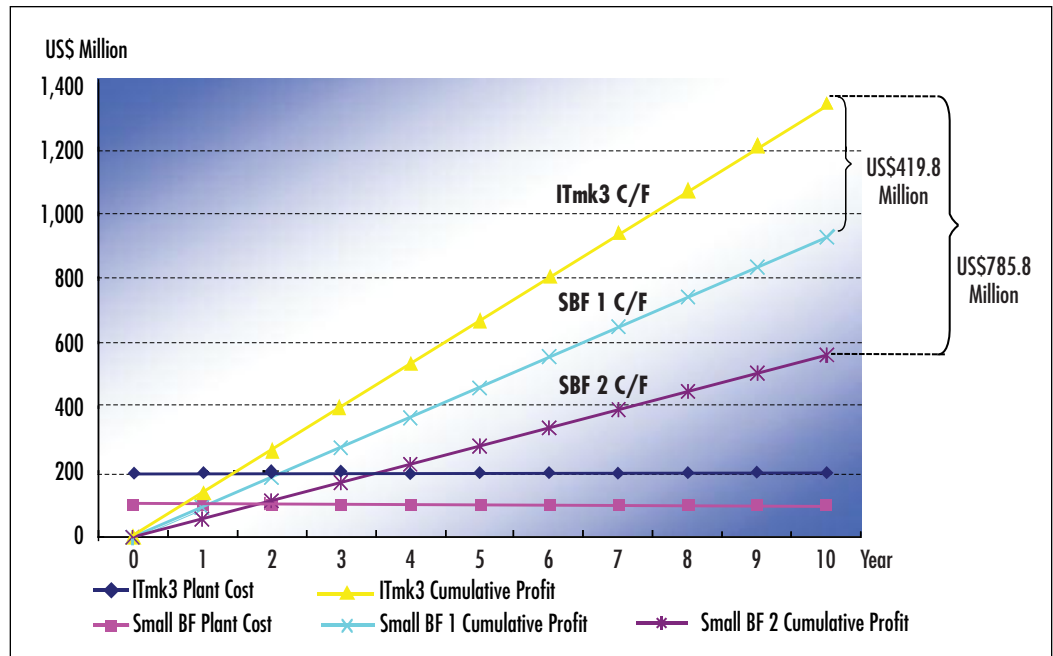


Figure 1 - Cumulative Cash Flow

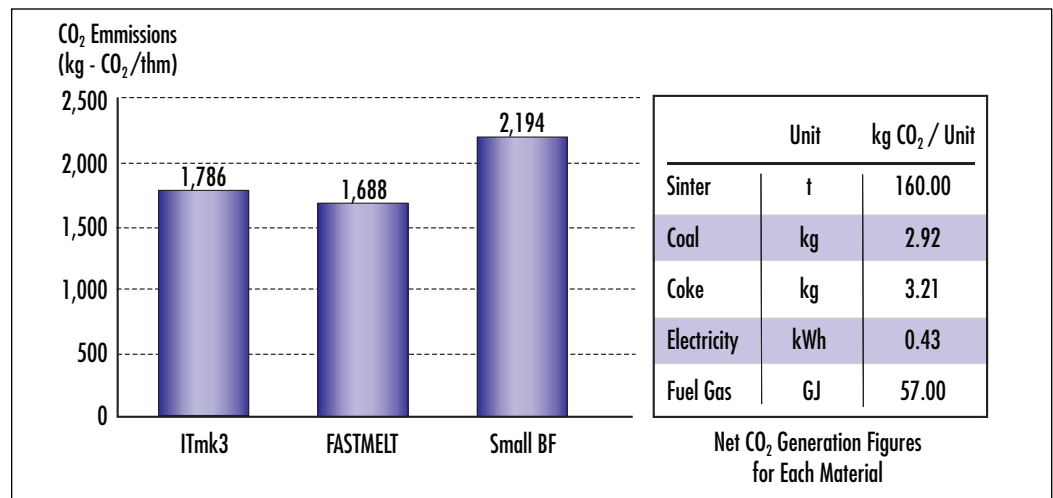


Figure 2 - Comparison for CO<sub>2</sub> Emissions

	Unit	kg CO <sub>2</sub> / Unit
Sinter	t	160.00
Coal	kg	2.92
Coke	kg	3.21
Electricity	kWh	0.43
Fuel Gas	GJ	57.00

Net CO<sub>2</sub> Generation Figures for Each Material

materials, more than a few companies plan to install mini/small blast furnaces. Moreover, in order to accommodate the growing steel demand, construction of an integrated iron and steel complex is planned in several countries.

Construction of an integrated iron and steel complex requires a long lead time, as well as a huge investment. Additionally, such mass production may not work as well as it used to, given the present iron ore and coke market situations. Although development of a mini/small blast furnace seems to be competitive in initial cost, it is not an efficient system from the long-term view and for the sustainable development of the iron and steel industry when considering the environmental impacts.

Two RHF-based processes, namely ITmk3 and FASTMELT, are outstanding technologies which may provide solutions to the Southeast Asian region. In these volatile times, it is worthwhile to study not only past business models, but also new models including breakthrough technologies when evaluating an ironmaking project.

# Development of EAF Dust Recycling and Melting Technology Using the Coal-based FASTMELT® Process

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Kobe Steel, Ltd.

Editor's note: this article was adapted from a paper presented at the SEAIISI Conference in May 2008.

## INTRODUCTION

The accumulation of EAF dust and its disposal have become a serious issue worldwide. EAF dust contains valuable metal resources such as iron, zinc, lead and other elements. Effective recovery of these metals would contribute to the development of a sustainable society.

Kobe Steel, Ltd. and Midrex Technologies, Inc. have developed and commercially applied the FASTMET® Process for both direct reduced iron (DRI) production and steel mill waste recycling. Since 2003, Kobe Steel has carried out a process development project, including three years beginning in 2005, of pilot plant operations at Kakogawa Works in Japan. This project, titled "Development of Valuable Metal Recovery Technology by Using a Rotary Hearth Furnace (RHF)," was subsidized by Japan's Ministry of Economy, Trade and Industry (METI).

The purpose of the process development project was to:

- Produce DRI from EAF dust using the coal-based FASTMET® Process.

- Effectively recover valuable metal resources such as zinc in the flue gas.
- Melt the DRI into hot metal using the coal-based FASTMELT® Process to increase added value of recovery metal. As a result of the study and pilot plant operations, the following points are discussed in this article:
  - The FASTMET Process offers a solution to EAF dust recovery.
  - The FASTMELT Process enables the production of hot metal from iron ore or steel mill by-products.

## CHARACTERISTICS OF EAF DUST AND THE CONVENTIONAL RECYCLING METHOD

### EAF Dust

Table I shows the chemical composition of electric arc furnace (EAF) dust, which we acquired from EAF steelmakers. Table II shows the chemical composition of blast furnace (BF) wet dust and basic oxygen furnace (BOF) dust as a comparison. The main component of all the dust is iron oxide. EAF dust is especially high in zinc since it contains very fine particles smaller than one micron, making it difficult to agglomerate. In Japan, EAF dust is designated as a special management industrial waste. Moreover, because EAF dust includes dioxin, plants in Japan that recover zinc from EAF dust are designated as special facilities under the *Law Concerning Special Measures Against Dioxins*.

EAF Dust								
	Total Fe	Zn	Pb	C	CaO	SiO <sub>2</sub>	S	Cl
Group 1	31~33	17~19	1	3	3~4	4~8	0.4	1~4
Group 2	21~25	26~29	1~3	3~6	2~4	3~5	0.4~0.6	5~7

Table I - EAF Dust Chemical Composition (mass %)

BF and BOF Dust										
	Total Fe	C	Zn	Cl	F	S	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	SiO <sub>2</sub>
BF Wet Dust	31.8	37.6	1.2	0.07	0.16	0.70	0.2	0.6	3.1	4.1
BOF Dust	53.6	0.7	2.5	3.30	0.96	0.10	1.0	5.8	5.0	0.8

Table II - BF and BOF Dust Chemical Composition (mass %)

Location	By-product (Tons/Year)	RHF Dia. (m)	Start-Up
Nippon Steel Hirohata, No. 1	190,000	21.5	Apr - 00
Kobe Steel Kakogawa	14,000	8.5	Apr - 01
Nippon Steel Hirohata, No. 2	190,000	21.5	Feb - 05
Nippon Steel Hirohata, No. 3	190,000	21.5	Dec - 08

Table III - FASTMET® Commercial Plants

### Conventional Method of Recycling Steel Mill Dust

The Waelz Kiln process is a well-established technology that uses a rotary kiln to treat steel mill dust. Dust containing zinc oxide and a carbon source, such as coke, are charged into the rotary kiln and heated by combustion heat. Compared to the FASTMET Process, the rotary kiln has lower productivity because of a lower operating temperature and less contact between dust and coal. The temperature in the kiln is generally below 1,200° C to prevent “kiln rings” from forming. Kiln rings are accretions of material that build up on the inside of the kiln shell. Contact between dust and coal is not as good as in FASTMET because in the kiln process, coal is added separately from the dust; whereas, FASTMET uses a pellet with coal and dust combined.

Because of its lower operating temperature and inferior dust and coal contact, the Waelz Process achieves lower iron metallization and less dezincification than FASTMET. Therefore, the iron product cannot be used as a metallic in blast furnaces, basic oxygen furnaces and electric arc furnaces, and it must be disposed of in special landfills. Such disposal is becoming more difficult and expensive. Also, there is a growing trend toward zero emissions of steel mill waste and EAF dust.

### The FASTMET Process as a New Method of Recycling EAF Dust

FASTMET is an improved method of treating EAF dust. Several plants using the FASTMET Process to recycle steel mill waste have started up in Japan since 2000, and they have achieved high operating rates and good productivity. Several other plants are under construction.

Table III shows the three operating commercial plants in Japan that use the FASTMET Process.

### Comparison of the RHF Process and Rotary Kiln Process

The characteristics of the FASTMET Process, versus the rotary kiln process, are as follows:

- FASTMET operates at higher temperatures, over 1,300° C.
- FASTMET achieves higher metallization and dezincification because of the higher temperatures and higher uniformity of the mixed EAF dust and carbon source before they are fed into the RHF.
- FASTMET DRI can be used as a metallic in BFs, BOFs and EAFs because of the higher metallization and recovery of zinc in the DRI.

- Fines generation is lower because the agglomerated raw materials (iron ore and coal) do not roll, but are stationary on the rotary hearth.
- The zinc content of the recovered flue dust is higher because the amount of dust generated is lower and the dust can be separated in the flue gas system.
- The amount of dioxin in the DRI is lower because the dioxin in the EAF dust is broken down under high temperatures.
- The amount of dioxin in the flue gas is lower, because the hot flue gas from the RHF is cooled rapidly in the flue gas system to prevent de novo formation.

### The PROCESS DEVELOPMENT PROJECT Themes

The KSL project for METI includes an RHF and melter. The RHF was designed to produce DRI from EAF dust, with the melter generating hot metal from the DRI using oxygen and a carbon source.

In order for the FASTMET/FASTMELT Process to treat EAF dust, the following technical themes were undertaken:

- Produce agglomerated mixed material in the form of briquettes.
- Produce higher strength DRI from the briquettes.
- Recover a higher amount of zinc in the form of zinc oxide in the flue gas.
- Prevent erosion, corrosion and adhesion in the flue gas system. (Some of the elements in EAF dust, especially zinc, are ten times higher than that of other steel mill waste.)
- Confirm that the amount of dioxin in the flue gas is lower.
- Confirm that the DRI produced can be melted into hot metal using the FASTMELT Process.

The project was carried out at Kobe Steel's Kakogawa Works. A photo of the FASTMET pilot plant, known as the Kakogawa Pilot Plant (KPP) is shown in Figure 1.

### Project Schedule

The project was begun in 2003 and demonstration operation at Kakogawa Works was carried out until 2007. The total period from start to finish was about five years.



Figure 1 - Kakogawa Works FASTMET® Pilot Plant

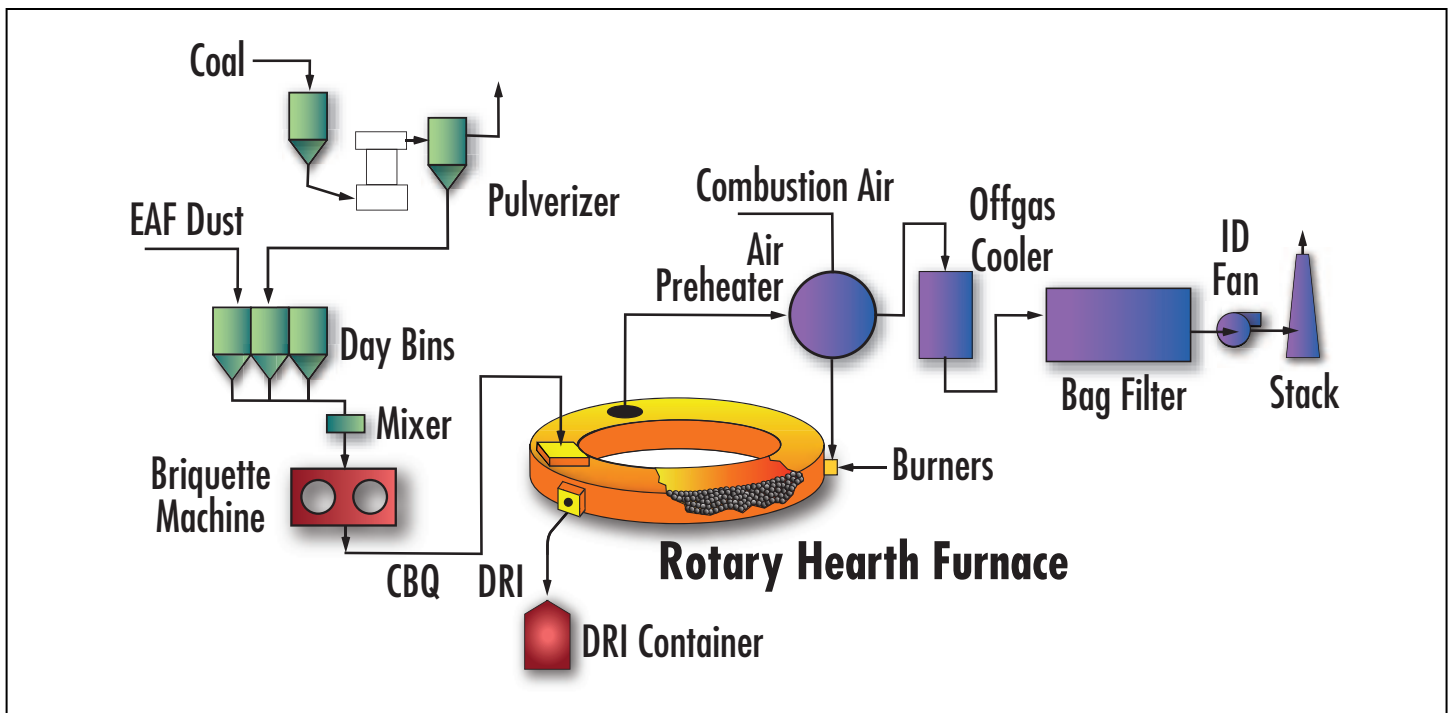


Figure 2 - Kakogawa Pilot Plant Flowsheet

**PILOT PLANT TESTS USING EAF DUST  
Process Flowsheet and Equipment**

Figure 2 shows the process flowsheet for the FASTMET pilot plant and Table IV provides details of the feedstock and equipment. The Rotary Hearth Furnace has the capacity to process approximately 20,000 tons of dust per year.

EAF dust, pulverized coal for the reductant and a binder are mixed together. Then the mixture is agglomerated into cold briquettes (CBQ). The CBQ, fed into the RHF, are heated rapidly to temperatures of 1,200° C -1,400° C. The iron oxide in the CBQ is reduced to metallic iron. Zinc, lead and other volatile substances are vaporized and reoxidized in the flue gas.

The product DRI goes into the DRI container and is cooled with nitrogen. The vaporized substances in the flue gas are collected in a bag filter and the zinc is recovered as zinc oxide. The sensible heat of the flue gas is recovered by combustion air using a heat exchanger.

Item	Description
<b>Feedstock</b>	Iron ore, EAF Dust Bituminous, Non-coking Coal
<b>RHF</b>	11.5 meter OD Capacity: 20,000 t/y Feed Offgas Temperature: max. 1,400° C

Table IV - Feedstock and Equipment Details

**Characteristics of EAF Dust and Coal**

The chemical compositions of the EAF dust and coal used in the project are shown in Table V. EAF dust was classified into two groups. Group I contained higher total iron (Total Fe) and lower zinc.

EAF Dust								
	Total Fe	Zn	Pb	C	CaO	SiO <sub>2</sub>	S	Cl
<b>Group 1</b>	31~33	17~19	1	3	3~4	4~8	0.4	1~4
<b>Group 2</b>	21~25	26~29	1~3	3~6	2~4	3~5	0.4~0.6	5~7

Coal				
C	H	N	O	S
83.4	4.1	2.1	0.9	0.3

Table V - Chemical Compositions of EAF Dust and Coal

<b>IN</b>	EAF Dust	263 t
	Coal and other	63 t
	<b>Total</b>	<b>326 t</b>
<b>OUT</b>	DRI	144 t
	Zinc oxide	79 t
	Gas and other	103 t
	<b>Total</b>	<b>326 t</b>

Table VI - Mass Balance of RHF Using EAF Dust

**Test Results**

Table VI shows the mass balance for the project. The amount of EAF dust treated was 263 tons, which produced 145 tons of DRI

and 79 tons of crude zinc oxide. The remaining output was vapor and other constituents.

Figure 3 shows the material flow and photos of the raw materials, cold briquettes and DRI.

Table VII shows the chemical composition of the DRI and the baghouse dust under the test conditions. The DRI metallization averaged 73 to 88 percent.

The residual zinc content in the DRI was 1-4 percent, giving a dezincification degree of 91-98 percent. The baghouse dust had 57-70 percent zinc as zinc oxide, with less than one percent iron. The dezincification degree is calculated using the following formula:

$$\text{De-zinc (\%)} = \{1 - (\text{ZnO in DRI} / \text{T.Fe in DRI}) / (\text{ZnO in dry ball} / \text{T.Fe in dry ball})\} \times 100$$

Most of the zinc in the EAF dust was vaporized and then re-oxidized in the flue gas.

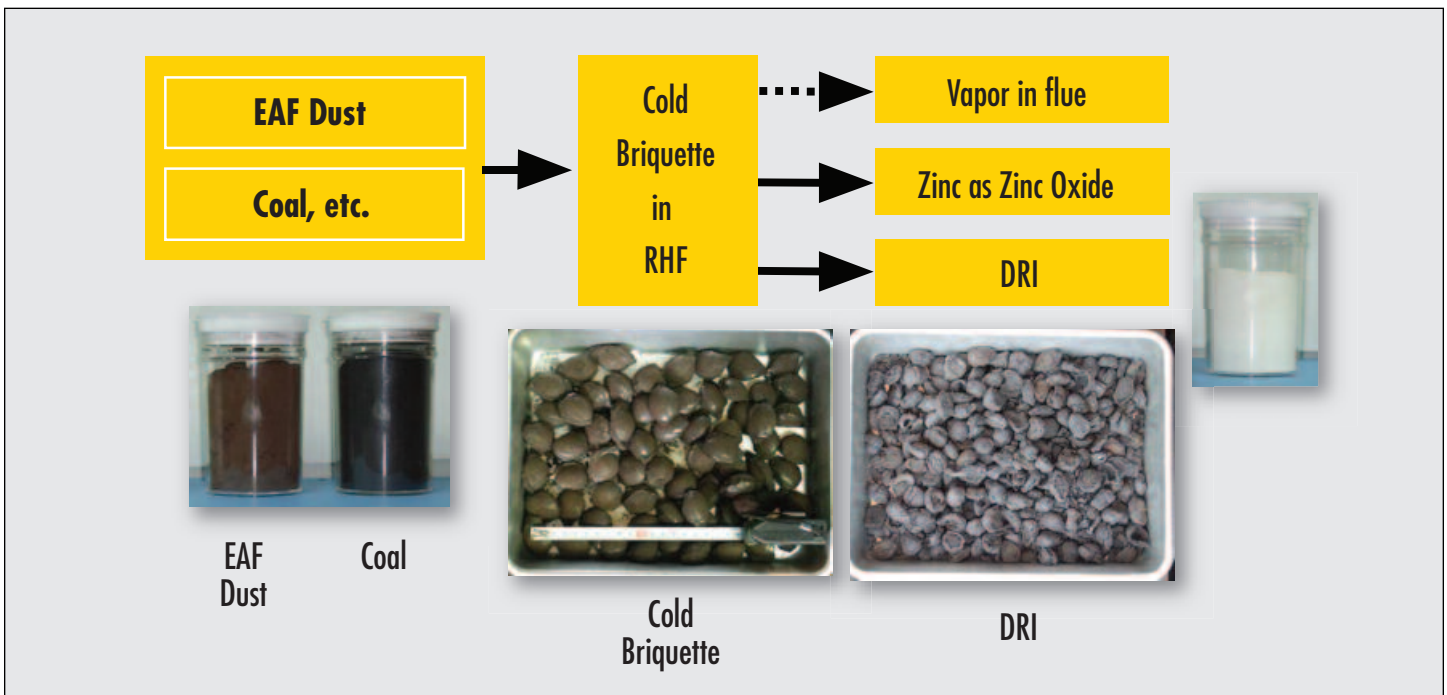


Figure 3 - Material Flow and Photos

DRI and Baghouse Dust									
	(Mass %)	Total Fe	Metallic Fe	Zn	Pb	C	CaO	SiO <sub>2</sub>	S
<b>DRI</b>	<b>Group I</b>	46 – 53	40 – 46	0.7 – 2.4	0.1	5 – 11	5 – 8	9 – 13	0.6
	<b>Group II</b>	42 – 50	35 – 41	1 – 4	0.1 – 0.6	3 – 15	6 – 12	8 – 14	0.6 – 1.0
	Average Met (%)		73 – 88	De-Zn Degree (%)		91 – 98	De-Pb Ratio (%)		87 – 97
	(Mass %)	Total Fe	Zn	Pb	C	CaO	SiO <sub>2</sub>	S	Cl
<b>Crude Zinc Oxide</b>	<b>Group I</b>	0 – 0.2	64 – 70	3 – 4	0 – 0.1	0.1 – 0.2	0.1 – 0.2	0.4	5 – 8
	<b>Group II</b>	0 – 0.7	57 – 62	4 – 6	0 – 0.1	0.1 – 0.8	0.1 – 0.2	0.2 – 0.5	9 – 16

Table VII - Chemical Composition of DRI and Baghouse Dust

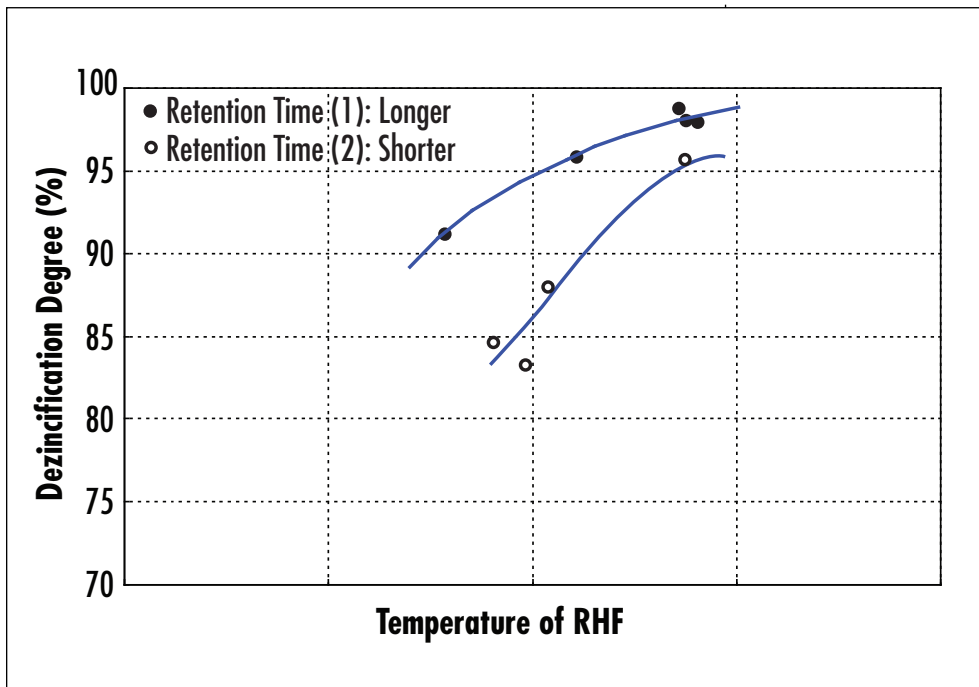


Figure 4 - Relationship of Temperature of RHF and Dezincification

NO <sub>x</sub> (ppm)	SO <sub>x</sub> (ppm)	Dust (g/Nm <sup>3</sup> )	Dioxin (ng-TEQ/Nm <sup>3</sup> )
<40	<50	<0.015	<0.1

Table VIII - Emissions Data of RHF at KPP

Figure 4 shows the relationship between the temperature in the RHF and dezincification degree. As the temperature in the RHF increases, the dezincification degree also rises. In addition, the dezincification degree increases with longer retention time.

Table VIII shows the emissions data of the RHF at KPP. Samples were taken at the outlet point of the bag filter. The NO<sub>x</sub> content in the flue gas was controlled to less than 40 ppm (12 percent O<sub>2</sub>) and the dioxin content was lower than 0.1 ng-TEQ/Nm<sup>3</sup>.

### DEVELOPMENT OF THE COAL-BASED FASTMELT PROCESS Development Features of FASTMELT

KSL and Midrex Technologies, Inc. offer the FASTMELT process, using an Electric Ironmaking Furnace (EIF) to melt hot DRI and produce hot metal. Figure 5 shows the features considered in the development of the coal-based melter, which is a cylindrical stationary furnace operating at low pressure. The ultimate goal is continuous operation of the coal-based melter.

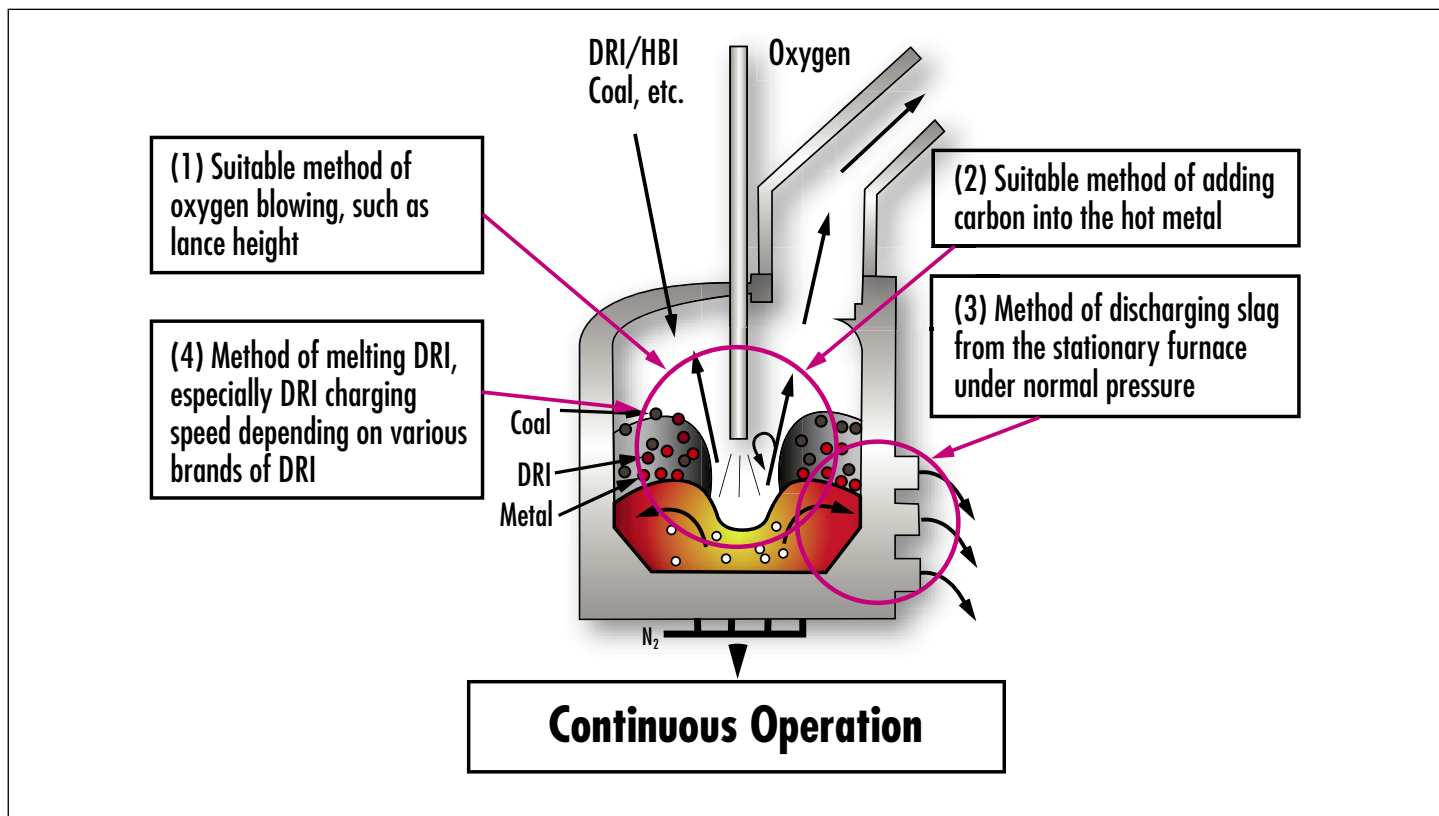


Figure 5 - Coal-based Melter Features

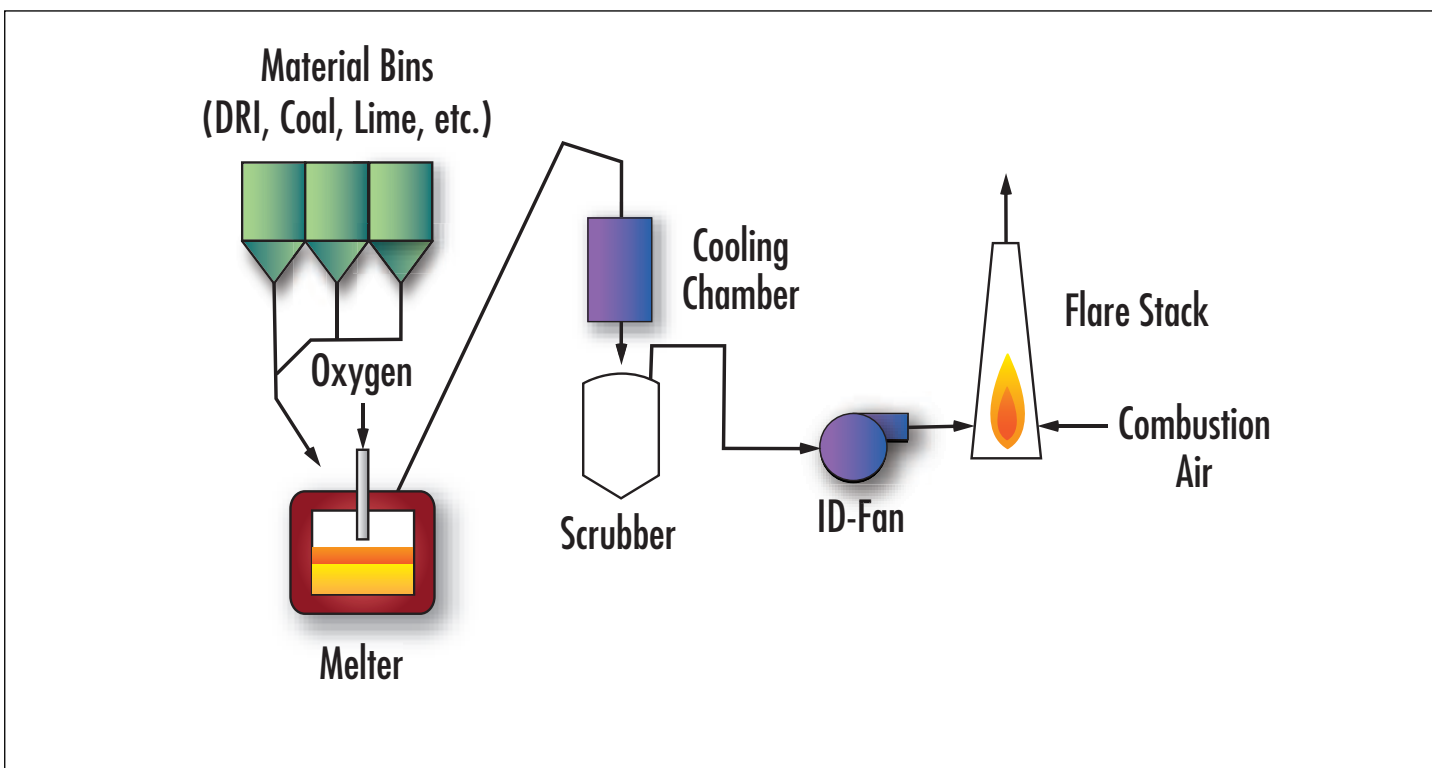


Figure 6 - Process Flowsheet of the Coal-based Melter

Cylindrical Stationary Furnace Method
Tapping: Drilling
Dimension: I.D. 2m x 2.6m
Capacity: 16,000 t/y Hot Metal

Table IX - Profile of Coal-based Melter

Feed Material	Metallization	Total Fe	Metallic Fe	C
Iron Ore	86.0	77.3	66.5	7.9
EAF Dust Carbon Steel	82.4	58.1	47.0	7.2
EAF Dust Stainless Steel	73.2	35.4	25.3	3.1

Table X - Typical Chemical Composition of DRI (mass %)

**Process Flowsheet and Facility**

Figure 6 shows the process flow and Table IX provides details of the equipment for the coal-based melter. DRI, coal and other materials are charged into the melting furnace from the top by gravity. Oxygen is blown into the furnace from the top using lances, and input energy is obtained from the oxidation of carbon. The flue gas passes through a cooling chamber that cools the flue gas down to less than 500° C using atomized water. This is followed by a wet scrubber to remove dust. The flue gas then goes to an induced draft fan and then to a flare stack. Combustibles in the flue gas are completely burned before discharge to the atmosphere. The capacity of the facility is 16,000 tons of hot metal per year.

**Test Results**

A typical chemical composition of the DRI produced using various feed material is shown in Table X. Figures 7 and 8 show typical operations data during

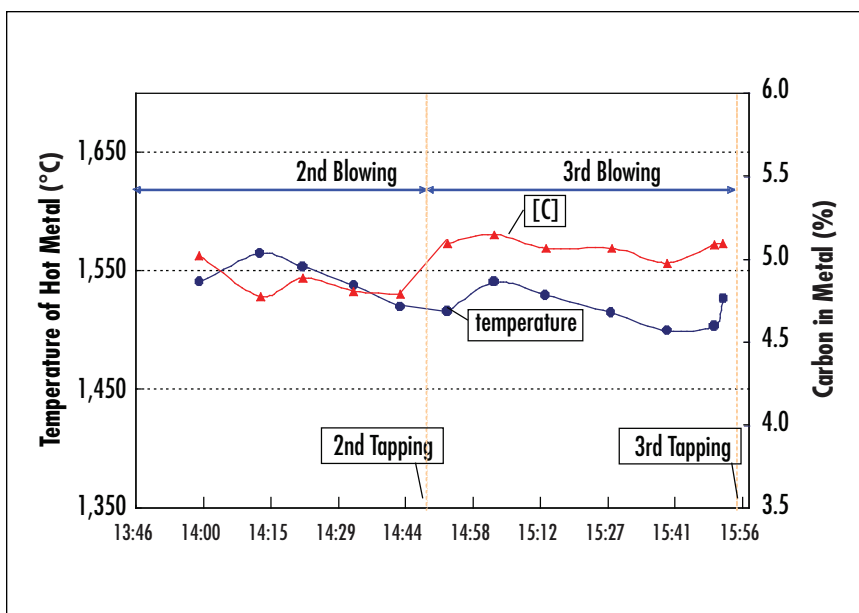


Figure 7 - Transition of Metal Temperature and Carbon Content

the testwork. The DRI charging rate was adjusted to control the temperature of the hot metal. The carbon content in the hot metal was kept above 4.7 percent.

Technical factors affecting the melting process were investigated during the numerous test runs.

The following results were achieved: development of suitable methods of oxygen blowing and lance height, adding coal, smooth tapping of hot metal iron using the coal-based melter.

**FASTMELT Plant**

The complete process flowsheet for a FASTMELT Plant is shown in Figure 9. DRI is produced in the RHF and fed hot to the melter to make hot metal.

**CONCLUSION**

Trials conducted at the Kobe Steel Kakogawa Pilot Plant with the support of METI provided the following results for the FASTMELT Process treating EAF dust and iron oxide:

- Development of an agglomerating technology to mix EAF dust and coal.
- Development of technology to achieve dezincification of over 95 percent, higher metallization and higher strength DRI than the rotary kiln process. As a result, the DRI can be used as a metallic feedstock for steelmaking, rather than being disposed of.
- RHF operations using EAF dust were undertaken without plugging, erosion and corrosion problems in the flue gas system. This is a challenge because EAF dust often contains ten times the amount of zinc as ordinary steel mill waste.
- Baghouse dust from the flue gas contained a higher zinc content than the rotary kiln product and less than one percent iron.
- NO<sub>x</sub>, SO<sub>x</sub> and dioxin emission levels were lower than for the kiln process. Dioxin emissions were less than 0.1 ng-TEQ/Nm<sup>3</sup>.
- The FASTMELT process produced hot metal from iron ore fines and coal.
- The basic characteristics for melting various types of DRI using oxygen and carbon were confirmed.
- Discharging slag from the stationary furnace under normal pressure was carried out smoothly.
- The cycle of DRI melting to produce hot metal and tapping were repeated successfully.

The coal-based FASTMET Process provides a viable method to recover valuable metals using a rotary hearth furnace. Based on the results gained from the pilot plant, we were able to develop both the basic concept and engineering for the FASTMET Process. Taking an extra step using the FASTMELT Process, we successfully produced hot metal from the DRI. Based on these

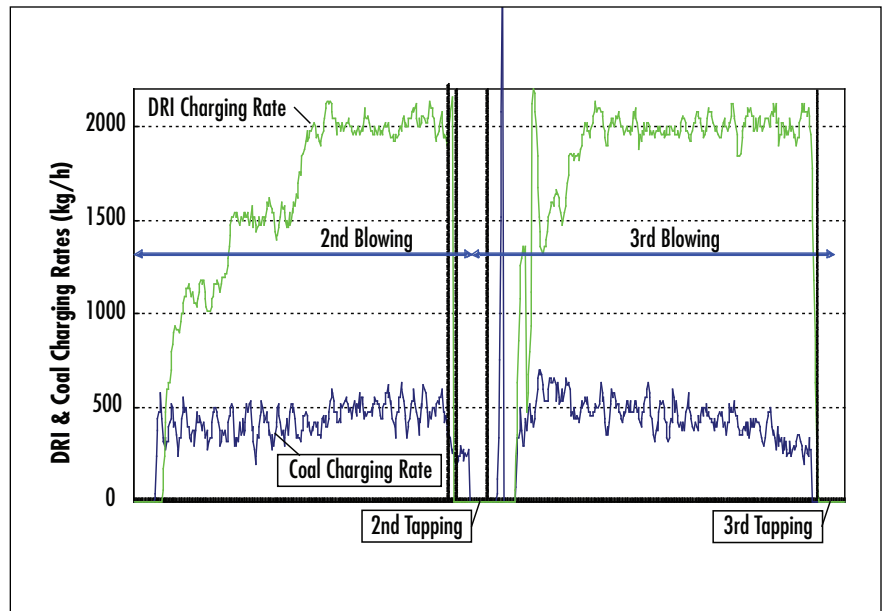


Figure 8 - Transition of DRI and Coal Charging Rates

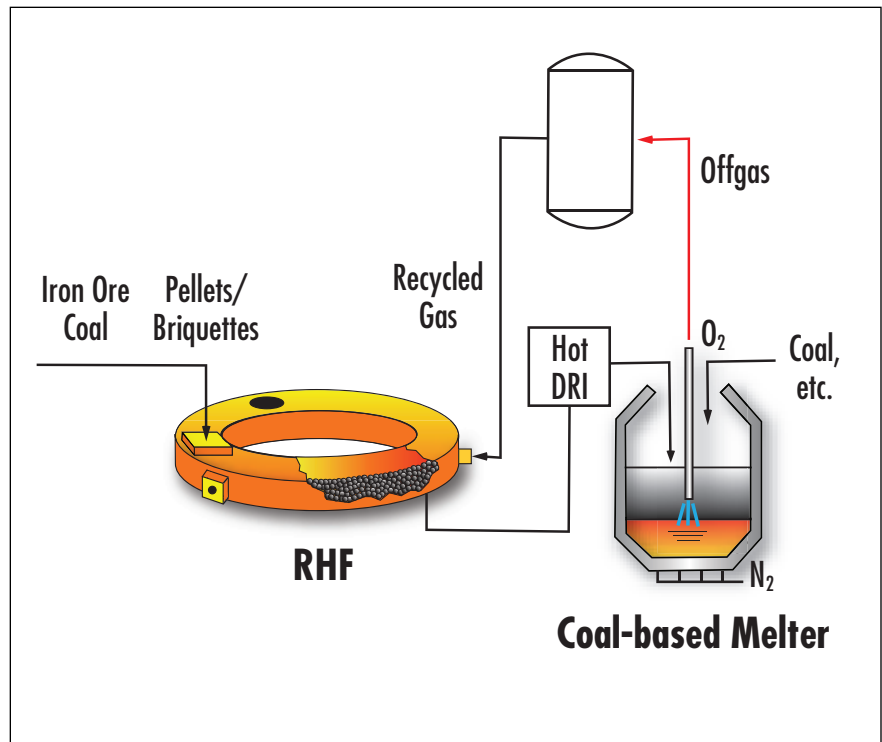


Figure 9 - FASTMELT Plant Flowsheet

results, Kobe Steel is promoting commercial plants using the FASTMET Process to make DRI and the FASTMELT Process to make hot metal.

When EAF dust is used as the raw material, both processes can be used not only to recycle EAF dust, but also to effectively collect difficult-to-recover zinc, which can be subsequently recovered. In this way, these two innovative direct reduction processes can reduce the burden on the environment and contribute to the development of a sustainable society.