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DIRECT REDUCTION OF IRON ORES - THE EXAMPLE OF INDIA*

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In extraction metallurgy, iron as a base metal has probably received more attention than any other metal. There has never been a slack in the development of new concepts and techniques of producing iron. Practically all types of reactors and a wide variety of reductants have been proposed for its extraction and production. The various processes of extraction of iron can be broadly classified depending on the product, as follows:

- Processes producing molten/hot metal; and
- Processes producing solid direct reduced iron (DRI).

Among the processes for producing hot metal, the classical blast furnace has become synonymous with the extraction of iron. Unlike in steelmaking technology, there has not been any revolutionary change in the iron-making process during the last several centuries, though refinements have been taking place from time to time. As a result, the blast furnace process has emerged stronger, despite its dependence on coking coal; its economic viability only at relatively large capacity; its higher investment requirements; and the environmental pollution associated with it.

With a view to overcome these limitations of the age-old blast furnace, alternative processes for the production of hot metal have been developed recently, based on the smelt reduction technology. These new processes are still in different stages of development.

Historically, the extraction of iron employing the direct reduction processes (without the use of coking coal) pre-dates the blast furnace technique. The interest in these processes has been renewed from time to time during the last two centuries. Although hundreds of process designs and techniques have been patented and promoted, only a countable few have survived after the first commercial unit based on the process was set up. The processes producing DRI came to be developed with one or more of the following objectives in view:

- to produce melting stock for steelmaking,
- to pre-reduce feed material for electric smelting, and
- to process and recycle waste products as feed material for the smelting plants.

DRI processes utilise either natural gas or coal as reductant. The commercially proven direct reduction (DR) processes coupled with electric arc furnace (EAF) steelmaking have offered a viable alternative to the blast furnace-basic oxygen furnace (BF-BOF) route for the installation of integrated plants under specific local conditions. The DR-EAF route is eminently suited for midi plants to serve limited markets and to keep down investment. It also offers scope for expanding the plant in small incremental steps.

World situation

The total world production of iron in terms of hot metal (HM) and direct reduction (DRI) is given in Table 1.

TABLE 1 - WORLD IRON PRODUCTION[1][2][3]

Year		Production, (mill. tons) HM	DRI	Total	Percentage share HM	DRI	Total
1970	..	427	0.73	427.73	99.8	0.2	100
1975	..	469	2.70	471.70	99.4	0.6	100
1980	..	508	7.20	515.20	98.6	1.4	100
1985	..	499	11.00	510.00	97.8	2.2	100
1986	..	489	12.70	501.70	97.5	2.5	100

It needs to be mentioned that the production of hot metal indicated in Table 1 includes the output of both blast furnace and electric pig iron furnace (EPIF). In 1986, the world output of EPIF was about 4 million tons which is only about 0.8% of the total hot metal. From the table it will be noted that the share of hot metal in the world iron production has declined by about 2% during the last decade and a half. With regard to the production of DRI, its share has risen from a negligible 0.2% in 1970 to 2.5% of the world production of iron in 1986; in actual quantity, this represents an increase of about 17 times. Since iron is predominantly utilised for steel production, it may be interesting to examine the changes in the world steel scenario.

The world steel production rose from 595 million tons in 1970 to an all-time high of 745 million tons in 1979; however, thereafter, it has been averaging at about 700 million tons.

A look at the trends in steel production during the decade 1975 to 1985 (Table 2) indicates that while the annual crude steel production in the developed countries has fallen, the contribution of the developing countries and the centrally planned economies has been progressively increasing. This is not an isolated incident, but an indication of the structural changes taking place in the different economies. It is expected that the developing countries will continue pursuing their present course of industrial and infrastructure development which will be reflected in the further growth of steel production in these countries. Similarly, it is anticipated that steel production in the centrally planned economies may continue to grow in the foreseeable future and their share in the 15 years beyond 1985 would be almost a mirror image of their share in the world production during the preceding 15 years.

TABLE 2 - WORLD STEEL PRODUCTION[4]

	Developed countries		Developing countries		Centrally planned economies		Total world	
	Million tons	%	Million tons	%	Million tons	%	Million tons	%
1975 ..	391	61	33	5	219	34	643	100
1980 ..	407	57	57	8	252	35	716	100
1985 ..	375	52	76	11	266	37	717	100

Iron and steel has been a traditional industry in the developed countries and in some of the centrally planned economies. The bulk of the steel production in these countries is through the blast furnace route. It is interesting to note that about 80% of the world production of DRI was obtained from the developing countries. It may, therefore, be said that the increase in the steel production of the developing countries is reflected in the increasing share of DRI (or alternative routes of iron-making) in the global iron production.

With regard to the future trend, the share of the electric arc furnace may further increase in the developed countries. However, due to the easy availability of scrap at reasonable prices as well as the high cost of energy, (reducing agent), domestic production of DRI may not be favoured in these countries. The current share of world DRI capacity in developed countries is about 25%. Generally, therefore, the alternative routes of ironmaking appear to present a greater possibility of application in the developing countries. It may, however, be noted that even amongst the developing economies, the countries where steel production is expected to grow rapidly and in bulk, for example in the People's Republic of China, South Korea, Taiwan, Brazil etc, the blast furnace route may also find a greater application in the coming years. On the other hand, in developed countries under special conditions, such as that in USA, there will be a further reduction in the output of steel by the BF route due to the closure of inefficient units and the high investments needed to conform to the stringent pollution control laws. Very likely, a part of this capacity will be replaced by electric arc furnace plants. Some of these electric furnace plants may consider the installation of alternative ironmaking processes, mainly to control the impurities level in the finished steel. It is difficult to control these in steel produced with 100% scrap charge.

The steel situation in India

The existing crude steel capacity of the country is estimated at about 19 million tons. The growth in the steel production during the last 10 years is shown in Figure 1. The steel is produced by various processes in India namely, BOF, open hearth (including Duplex) and electric arc furnaces. The growth in the production of electric arc furnace steel is also indicated in Figure 1. The share of electric arc furnace steel in the total crude steel production has increased from about 12% in 1977-78 to about 27% in 1987-88 (Figure 2). Based on the projection of the past trends in the growth rate of production, it is estimated that by the end of this century, the total crude steel production may be of the order of 30 million tons, of which the share of the electric arc furnace may be about 35%.

The metallic requirements of steel production are met through hot metal, scrap and direct reduced iron (DRI). The existing ironmaking capacity in India is about 16 million tons and the share of different processes is given in Table 3.

TABLE 3 - SHARE OF IRONMAKING CAPACITIES BY DIFFERENT PROCESSES IN INDIA[8]

		Mill. tons/year	Share %
Blast furnace	..	15.67	97
EPIF	..	0.14	1
DRI (Rotary kiln)	..	0.27	2
Total	..	16.08	100

The iron requirements for steel production in 1986-87 was about 14.5 million tons comprising 59% hot metal, 37% scrap and 4% DRI as shown in Figure 3.[5]

Scrap situation in India

The growth of the electric steel sector depends on the availability of the essential inputs, namely melting stock and power. Till 1977-78, the indigenous scrap availability was adequate to meet the requirements of the electric furnace steel production. However, the demand for scrap overtook the indigenous availability, when the electric furnace steel production crossed the one million ton per year mark. In order to meet the increasing demand, the country has had to import scrap and sponge iron.

During 1981-82, a total of almost 600,000 tons of scrap was imported. By 1986-87 the quantity had risen sharply to almost 2 million tons. In the current year, the imports are expected to be between 2.5 million to 3 million tons. This trend is expected to continue in the immediate future.

The recent trends in the international scrap market indicate that the scrap will be an increasingly scarce commodity in future and it can be expected that the price of scrap to be imported by India in future will be higher than the price paid in the past. Further, continued dependence on imported scrap would also adversely affect the already negative trade balance. The Government has, therefore, been encouraging the installation of direct reduction plants.

Investigations on Direct Reduction Processes

Systematic investigations for commercial application of direct reduction proceses in India started in the early 1960's. The known reserves of petroleum fuels at that time were very meagre and that too isolated in the north eastern region of the country with a difficult transport infrastructure. Therefore, only coal based processes were of interest to India. This situation continued until very recently when the availability of natural gas in various parts of the country has become known.

The first series of tests to be conducted was in connection with a small steel project based on the use of magnetite quartzite ore and lignite. While the iron ore can be beneficiated to produce high grade concentrates and pellets, the use of lignite was posing problem. Thereafter for more than a decade, similar investigations were conducted with various raw materials, particularly hematite ores and sub-bituminous coals. However, none of the projects came to be implemented, mainly due to the status of the DR processes then and the characteristics of the Indian raw materials, particularly coal. While the potential of the coal-based DR processes was appreciated, it was recognised that these processes are highly sensitive to the quality of raw materials and therefore, a study of the behaviour of the raw materials on a larger scale was crucial. It was in this context that UNDP/UNIDO agreed to assist in setting up in India a semi-commercial plant of Sponge Iron India Ltd (SIIL).

While initially the testing of raw materials was carried out by the processss suppliers, progressively various Indian agencies set up relevant testing facilities. The National Metallurgical Laboratory (NML) of India has studied the behaviour of a large number of Indian iron ores and coals to assess their suitability for use in the coal based DR processes. Small scale testing facilities have also been installed at SIIL as well as at the Research and Development Centre for Iron and Steel (RDCIS) of the Steel Authority of India Ltd at Ranchi. Besides, the Tata Iron and Steel Company Ltd has also set up laboratory and pilot plant facilities for testing raw materials which led to the development of the Tata Direct Reduction (TDR) process. Indian agencies have carried out extensive work in identifying the suitability of the different raw materials - iron and coal - for use in the rotary kiln DR processes. This has helped in eliminating some options, while identifying the raw materials sources for new projects. During the project implementation, however, the process suppliers also carry out the requisite tests needed for firming up the design parameters and also to offer the requisite performance guarantees.

Some of the Indian raw materials tested are indicated in Table 4. It would be noted that Indian iron ores/pellets have been tested both for the purpose of coal-based reduction and gas-based reduction. The investigations indicated that not all high grade ores are suitable for direct reduction. Many of the ores tend to decrepitate; and other considerations such as reducibility, phosphorus content etc are of significant importance in selecting the oxide feed for the above

TABLE 4 - LIST OF SOME OF THE INDIAN RAW MATERIALS TESTED FOR DRI PRODUCTION

A. COAL-BASED ROTARY KILN PROCESSES

Iron Ore

Raw materials	Fe %	SiO_2 %	Al_2O_3 %	P %	S %	Remarks
Bailadila	63 to 68	0.43 to 1.59	0.49 to 3.08	Traces to 0.05	Traces to 0.08	Suitable
Dalli-Rajhara	61.9 to 65.7	1.1 to 2.8	1.7 to 3.4	0.04 to 0.088	0.005 to 0.011	Suitable; some types generate higher amounts of fines
Surajgarh	60 to 68	0.35 to 6.10	0.68 to 7.32	0.017 to 0.2	0.033 to 0.005	Suitable
Banspani	68.8	0.7	0.5	0.012	0.005	Suitable
Bellary-Hospet	63.25 to 65.82	1.4 to 2.5	1.5 to 4.0	0.03 to 0.08	Traces to 0.04	Friable laminated type, not suitable

Non coking Coal

Raw materials	Moist %	Ash %	V.M. %	F.C. %	Remarks
Karanpura	8 to 10	14 to 28	26 to 29	37 to 45	Generally found fuitable; however, there are deposits containing coals with high ash content which is the main constraint in the performance of DR plants in India
Singareni	7 to 9	15 to 24	24 to 30	42 to 49	
Talcher	7 to 9	13 to 18	33 to 35	41 to 44	
Rampur-Hingir	6 to 8	11 to 22	23 to 30	40 to 57	
Ranigunj	4 to 10	12 to 22	31 to 35	40 to 45	
Korba	5 to 9	25 to 30	20 to 25	40 to 45	

B. GAS-BASED DR PROCESSES

Iron Ore

Raw materials	Fe %	SiO_2 %	Al_2O_3 %	P %	S %	Remarks
Bailadila	63 to 68	0.43 to 1.59	0.49 to 3.08	Traces to 0.05	Traces to 0.08	Suitable
Banspani	68.8	0.7	0.5	0.012	0.005	Suitable
Sonshi	66	<-2.4 to 2.8-> (SiO_2 + Al_2O_3)		0.015	0.005	Suitable
Bellary Hospet	63.25 to 65.82	1.4 to 2.5	1.5 to 4.0	0.03 to 0.08	Traces to 0.04	Friable laminated type not suitable.

Pellet

Raw materials	Fe %	SiO_2 %	Al_2O_3 %	P %	S %	Remarks
Kudremukh	65	2.75	0.5	0.01	0.01	Pellets produced in laboratory scale were tested and found suitable.

processes. With regard to coal, it is noted that apart from chemistry, the reactivity, ash fusion temperature and caking properties are important considerations.

Considering the availability of domestic raw materials, India has developed its own standards for raw materials to be used for direct reduction processes. Extracts from relevant Indian standards are presented in Table 5. These are somewhat different than qualities of raw materials used elsewhere (Tables 6 to 8).

Based on the available information on raw materials and other considerations, an overall study at the national level has been prepared to identify areas where coal-based DR plants may be installed. Such a study serves as a guideline in formulating specific projects.

INDUSTRIAL EXPERIENCE

Three different coal based rotary kiln direct reduction processes are in operation in India. An another unit based on a fourth process is in an advanced stage of construction. The first gas-based sponge iron plant is under implementation. The existing/under construction DR plants in India are listed in Table 9 and the experience gained at the different operating plants are briefly discussed below. The geographic locations of the operating/under construction DR plants and the sources of raw materials for DRI production are shown in Fig. 4.

Sponge Iron India Ltd

The semi-commercial direct reduction plant of Sponge Iron India Ltd (SIIL) was set up by the Government of India with the assistance of UNDP/UNIDO. The first unit with a capacity of 30,000 tons per year became operational

TABLE 5 - SPECIFICATIONS OF RAW MATERIALS FOR DR PROCESSES

	Acceptable for gas-based processes(a)		Acceptable for rotary kiln processes(a)	Indian Standards	
A. Oxide feed stock	Pellet	Lump ore	Lump ore	Pellet	Lump ore
Chemical analysis					
Fe, % min. ..	66	66	66	65	62
$(SiO_2+Al_2O_3)$, % max ..	3.5	3.5	4	4	7
S, % max ..	0.025	.025	0.02	0.03	0.03
P, % max ..	0.03	0.03	0.03	0.07	0.08
Physical characteristics					
Compressive strength, kg/pellet, min ..	200	-	-	200	-
Tumbler Index, min ..	92% +5mm	85% +5mm	85% +5mm	92% +6.3mm	
Decrepitation under reducing condition, max	5% -3 mm	10% -3mm			Should be minimum
Screen analysis ..	5-18 mm	5-50 mm	5-25 mm	+16 mm .. 5% max. -16+9mm ..85% min -5 mm ..3% max	+40 mm .. 2% max -40+25mm 10% max -5 mm .. 2% max

B. Non-coking coal	Not applicable	Acceptable for rotary kiln processes(a)	Indian Standards
Ash, % max ..		Depends on the type of coal available in the country	24
Volatile matter,% ..			28-34
Fixed carbon, % ..			By difference in prox. analysis
Sulphur, % max ..			1
Inherent moisture ..			0.8
Caking index, max ..		5	5
Ash softening temp. ..		Min. 100°C above the redn. temp. (which is about 1100°C)	Min 1175 ± 25°C; desirable 1250°C and higher
Reactivity ..		Should be adequate for generation of reducing gas	2/cm³ of CO per gram of carbon content, min.

NOTE:
(a) As generally indicated by process suppliers.

TABLE 6 - TYPICAL COMPOSITION OF SOME OF THE DR-GRADE OXIDE FEED USED IN DR PLANTS (3) (6) (7)

Source	Country	Fe %	SiO_2 %	Al_2O_3 %	CaO %	MgO %	S %	P %
A. GAS-BASED DR UNITS								
Ferteco lump	Brazil	68.0	1.20	0.90	0.08	0.02	0.007	0.04
Jangada lump	Brazil	67.6	0.79	1.54	0.02	0.02	0.008	0.05
Mutuca lump	Brazil	68.3	0.87	0.85	0.06	0.05	0.006	0.04
CVRD Med. MgO pellet	Brazil	67.7	1.06	0.51	0.77	0.73	0.003	0.02
LKAB MPRD pellet	Sweden	67.4	0.95	0.25	1.15	0.80	0.006	0.02
Oskol pellet	USSR	67.4	3.42	0.18	0.70	0.17	0.004	0.01
SIDOR pellet	Venezuela	66.7	1.30	0.80	1.60	0.60	0.011	0.05
B. COAL-BASED ROTARY KILN UNITS								
Postmasburg lump	S. Africa	65.4	3.62	1.45	0.20	0.10	0.012	0.03
Sishen lump	S. Africa	66.7	2.50	1.20	0.03	0.01	0.012	0.04
Urucum lump	Brazil	69.4	0.58	-	0.03	-	-	-
Iron sand conc.	New zealand	58	1.1	-	0.2	-	-	-
Bayaram lump	India	63	4.5	-	0.1	-	-	-
Banspani lump	India	67.21	1.79	0.93	Trace	Trace	0.005	0.027
Itabira pellets	Brazil	67	2.4	-	1.6	-	-	-

TABLE 7 - TYPICAL CHARACTERISTICS OF COALS USED IN ROTARY KILN PLANTS

Plant	SIIL, India	OSIL, India	Dunswart Iron & Steel Works, South Africa		ISCOR, South Africa	Scaw Metals, Germiston, South Africa		New Zealand Steel, New Zealand	Acos Finos Piratini SA. Brazil
Coal Source	Singareni India	Gidi, India	Duff, South Africa	Anthracite, South Africa	Witbank, South Africa	Arnot, South Africa	Eikeboom, South Africa	Waikato, New Zealand	Charqueadas. Brazil
DR process	SL/RN	ACCAR	CODIR		SL/RN	DRC		SL/RN	SL/RN
A. Chemical analysis									
Fixed Carbon, %	44	45-49	53	73	59	53.6	58.9	40	36
Volatile matter, %	22	28-30	24	9	26	30.5	28.5	38	23
Ash, %	24	20-27	16	9	14	10.2	9.7	4	32
Moisture, %	10	8	7	9	8	5.7	2.9	18	9
Sulphur, %	0.4	Upto 1.06	0.7	0.75	0.6	0.42	0.58	0.3	0.4
B. Net heating value									
Calorific value, kcal/kg	6,000	5,100	6,300	7,100	6,450	N.A.		6,631	4,600
C. Other properties									
Ash softening point, °C	1,160	Above 1,200	1,150	1,260	N.A.	N.A.		1,270	Above 1,250
Reactivity	Moderate	N.A.	Moderate	Moderate	N.A.	N.A.		High	High

TABLE 8 - TYPICAL ANALYSES OF NATURAL GAS USED IN SELECTED DR PLANTS[a]

Country		CH_4 %	C_2H_6 %	C_3H_8 %	CO_2 %
Argentina	..	89.8	6.2	1.7	0.6
Canada	..	93.1	4.2	0.3	0.3
Venezuela	..	80.8	8.1	3.2	7.3
Saudi Arabia	..	71.1- 90.3	8.3- 27.0	0.4- 0.3	1.0- 1.2
Qatar	..	77.5	1.1	0.3	3.7
Trinidad	..	90.0	5.3	2.2	0.7
Nigeria	..	94.1	3.2	1.3	0.2
Brazil	..	90.7	8.7	-	-
Indonesia	..	85.5	9.1	-	3.7
Mexico	..	96.6	2.6	-	0.4
India[b]	..	78.84- 98.03	1.35- 7.23	0.4- 4.59	Nil- 6.49

NOTES:

(a) Does not necessarily refer to the complete analysis.

(b) For the ESSAR plant, under construction.

TABLE 9 - DR PLANTS IN OPERATION/UNDER CONSTRUCTION IN INDIA

Plant	Location	Year of start-up	No. of units	Annual capacity tons
MERCHANT DR PLANTS				
Coal-based Rotary Kiln Units				
SIIL	Paloncha, Andhra Pradesh	1980/85	2	60,000
OSIL	Palasponga, Orissa	1983	1	150,000[a]
IPITATA	Joda, Orissa	1986	1	90,000
BSIL	Chandil, Bihar	Dec. 1988	1	150,000[b][c]
Gas Based DR Unit				
ESSAR	Hazira, Gujarat	1989	2	880,000[b]
COMPOSITE STEEL PLANTS				
SISCO	Bhandara, Maharashtra	Sept/Oct 1988	1	150,000[b]

NOTES:
(a) The plant capacity IS reported to have been derated.
(b) Units under construction.
(c) Includes 25% additional capacity.

in end 1980. The prime objective behind setting up this unit was to test raw materials available in the country at the semi-commercial level of operation and establish techno-economic feasibility of producing sponge iron using

100% coal as reductant. The plant is based on the SL/RN rotary kiln technology and was designed and engineered by Indian consulting engineers (M.N. Dastur & Company).

Encouraged by the operating success of the plant, the Government of India sanctioned the expansion of the plant by adding a second unit of like capacity. The second unit went into production in July 1985. The performance of the two units is summarised in Table 10.

TABLE 10 - PLANT PERFORMANCE OF SILL[a]

		Unit 1	Unit 2
Start-up	..	Nov. 1980	July 1985
Rotary kiln dimension	..	3 m dia x 40 m long	3 m dia x 40 m long
Rated capacity, tons per annum	..	30,000	30,000
Process technology	..	SL/RN	SL/RN
No. of campaigns completed on 1.12.87	..	22	7
Campaign life (days)			
- Highest	..	243	129
- Lowest	..	29	54
- Average	..	97	93
Cumulative production up to 30.11.87, tons	..	178,826	51,661
Product quality - Degree of metallisation, %	..	90 ± 2	90 ± 2
Capacity utilisation, %			
- 1980-81	..	75	
- 1981-82	..	91	
- 1982-83	..	78[a]	
- 1983-84	..	94	
- 1984-85	..	85	
- 1985-86	..	88	70[b]
- 1986-87		80[b]	84[b]

NOTES:

(a) Lower capacity utilisation due to partial diversion of capacity for test work.

(b) Lower capacity utilisation due to power restriction.

The major initial problems faced by the plant were material back flow at the kiln outlet, maintenance of appropriate temperature profile at the discharge end, dust build up in the dust settling chamber and waste gas scrubber and failure of air fans. Appropriate modifications were made to overcome these teething problems.

SIIL is now implementing a scheme of installing a briquetting plant for the -3 mm fines. These fines amount to about 10% of their total production and is currently wasted.

SIIL has been carrying out studies on the effect of using coal of varying ash contents on production and productivity. The test campaign to study the effect on productivity of using low ash (25% coal) with varying proportions of FC/Fe in the feed showed an improvement in productivity by 10/12% and lowering of coal consumption by about 150 kg per ton of DRI. Test work has also been carried out on the use of lignite to the extent of 25% in the coal injected. Tests have also been carried out on the use of different iron ores in India.

SIIL has been contracted by UNIDO for bulk scale testing of raw materials from Vietnam and for lab testing of raw materials from Nepal and Niger. These tests are in progress. Earlier, SIIL has carried out tests on the raw materials from Pakistan and Hungary. On the basis of the test results the possibility of converting an old cement kiln in Hungary for the production of sponge iron has been recommended to UNIDO.

Orissa Sponge Iron Ltd.

The next sponge iron project was installed at Orissa by Orissa Sponge Iron Ltd (OSIL) adopting Allis Chalmers (ACCAR) process. The plant was commissioned in March 1983. This unit is reported to be the first and the only ACCAR plant based on duel fuel, i.e. 80% coal and 20% fuel oil. The use of oil under Indian condition has not been beneficial.

Since its start-up, the OSIL plant has faced numerous problems arising out of changes in the raw materials characteristics, frequent interruption of power supply and some design constraints. The size of kiln and the off-gas system were designed to operate with 80% coal and 20% fuel oil where coal with maximum 20% ash content was considered. Today, the plant is forced to operate with coal ash of 35% and above. Moreover, due to economic considerations the throughput of coal has been increased to 95% with the installation of coal slinging device at the discharge end, resulting in an appreciable saving in totalenergy input and fuel cost per ton of DRI. The increased coal throughput has not only reduced the available kiln volume considerably but also increased excessive load to the off-gas system. Installation of raw materials preparation plants to supply calibrated iron ore and coal have also been incorporated later. The commissioning of diesel generator set has reduced considerably the problems arising out of frequent power interruption.

It has been reported that the plant capacity has been derated - depending on the raw materials used - it may perhaps be between 120,000 to 135,000 tons/yr. The plant's performance as reported is given in Table 11.

TABLE 1i - PERFORMANCE OF OSIL PLANT[7]

Year of start-up	..	March 1983
Size of the rotary kiln	..	4.0 m dia x 84.0 m long
Rated capacity	..	150,000 tons per annum
Plant performance		
Annual Production		
- 1984-85	..	60,000 tons
- 1985-86	..	80,000 tons
- 1986-87	..	70,000 tons
- 1987-88	..	About 90,000 tons
Product quality	..	Average 90% degree of metallisation
Normal campaign life	..	90-120 days
Maximum operating days in a campaign	..	171 days
Highest daily production on consistent basis for 20 days	..	350 tons per day
Maximum production in a month	..	10,255 tons (April 1986)
Capacity utilisation		
- 1984-85	..	40%
- 1985-86	..	53%
- 1986-87	..	47%
- 1987-88	..	60%

It is to be noted that all modifications and improvements are being brought about by OSIL themselves. The targetted production for 1988-89 is 110,000 tons. To counter the high moisture content of coal during the monsoon season, OSIL is considering installation of a coal drier.

IPITATA

IPITATA is the first commercial sponge iron plant using indigenous technology known as TISCO Direct Reduction (TDR) process. Based on the in-house research work and development efforts conducted with the approval of the National Council of Science and Technology, a 10-12 tons per day pilot plant was setup in the R & D division of Tata Steel and was run on a 3-shift basis since mid 1974 till end 1985. The R & D division carried out extensive evaluation of rotary kiln direct reduction at various levels including process development and quality verification of raw materials. The IPITATA plant, promoted by IPICOL and Tata Steel, is located at Bilaipada near Joda in Orissa and the commercial production started in April 1986. The plant performance as reported till March 1988 is given in Table 12. Non-availability of the proper quality of coal, hardware difficulties and frequent power failures are the major problems faced by the plant.

TABLE 12 - PERFORMANCE OF IPITATA PLANT

Start up	April 1986
Size of the rotary kiln	4.2 m dia x 72 m long
Rated capacity	90,000 tons per annum
Process technology	TDR
Production of acceptable grade (+2 mm) of sponge iron, tons	
- 1986 (9 months)	10,702
- 1987	26,690
Capacity utilisation - 1986	16%
- 1987	30%
Product quality	Min. 88 per cent degree of metallisation
Yield of iron in the finished product	90%-92%
Longest campaign days achieved till January, 1987	About 60 days
Kiln availability	85%(excluding breakdown)

Bihar Sponge Iron Limited

Bihar Sponge Iron Ltd (BSIL) is another coal-based, rotary kiln direct reduction plant which is in an advanced stage of construction at Chandil, Bihar. It is reported to be commissioned in December 1988. The important parameters of the project are given in Table 13.

TABLE 13 - IMPORTANT PARAMETERS FOR BSIL PROJECT

Expected year of start-up	..	December 1988
Size of the rotary kiln	..	4.8 m dia x 80m long
Annual capacity	..	120,000 tons plus 25% additional capacity
Process adopted	..	SL/RN

Sunflag Iron & Steel Co. Ltd

All the four DR plants discussed earlier are merchant units. The Sunflag Iron & Steel Co. Ltd (SISCO) is the first composite steel plant in India and has an annual capacity of 200,000 tons rolled products based on the DR-EAF route. It is in an advanced stage of construction at Eklari, Bhandara in Maharashtra. The DR unit is scheduled for commissioning in the third quarter of 1988. The steelmaking and rolling facilities are expected to be commissioned earlier. The DR unit has a capacity of 150,000 tons per annum. The important parameters of the DR plant is given in Table-14.

TABLE 14 - IMPORTANT PARAMETERS OF DIRECT REDUCTION PLANT FOR SISCO

General

Annual rated capacity of SISCO	..	200,000 tons of finished bars and sections
Direct reduction plant	..	1 x 150,000 tons per annum rotary kiln unit
Steel melting shop	..	1 x 50-ton EAF equipped with 40 MVA transformer for UHP application.
		1 x 50-ton ladle furnace equipped with 9 MVA transformer.
		1-3 strand continuous billet caster
Bar and section mill	..	1 single strand continuous mill

Particulars of DR plant

Expected start-up	..	Sept/Oct. 1988
Size of rotary kiln	..	5.0 m dia x 80 m long
Process adopted	..	CODIR

The electric arc furnace of SISCO is designed for continuous charging of sponge iron. This will be the first commercial installation in India adopting this system of charging.

Earlier, in 1968-69 in connection with another DR-based project, successful trials had been carried out with continuous charging of sponge iron produced from Indian raw material at Lurgi's pilot plant and shipped back for further trials in India.

ESSAR Steel Corporation Ltd

ESSAR Steel Corporation Limited (ESSAR) are setting up the first natural gas-based direct reduction plant in India for the production of hot briquetted iron (HBI). The plant located at Hazira in Gujarat, is in the initial stage of construction. The project is based on a second-hand plant, procured from Nord Deutche Ferro Werke (Nordferro) at Emden, West Germany. The Emden plant having capacity of 880,000 tons annual capacity, will be dismantled and re-erected at Hazira with certain modifications such as introduction of hot briquetting for the production of HBI.

Other projects

There are several other projects in different stages of planning. Some of these are based on the use of natural gas and others based on coal.

Uses of sponge iron

The bulk of the sponge iron produced in India and most of the DRI imported are used as melting stock in electric arc furnaces. None of the existing electric arc furnace plants are provided with continuous charging facilities and therefore, the amount of DRI used in these plants is less than 25/30 per cent.

The Sunflag Iron and Steel Company's composite plant will be the first plant in India to industrially utilise continuous charging of sponge iron totalling to about 70 per cent of the metallic charge.

The use of DRI as a coolant in the basic oxygen furnace has also been successfully tried out in India. The Tata Iron & Steel Co. Ltd. (TISCO) has utilised up to 110 kg of DRI produced at their IPITATA unit as coolant in their BOF shop. Also, utilisation of up to 80 kg of hot briquetted iron as coolant has been successfully tried out by TISCO in their BOF meltshop.

Economics of DRI

Recent estimates indicate that the plant capital costs for the production of DRI in India is about Rs 5000 per ton (equivalent to about US $ 385 per ton) for coal based DR units of 150,000 tons per year capacity. Compared to this a gas-based plant of 400,000 tons per year capacity would require about Rs 4000 per ton (equivalent to US $ 346 per ton). These costs could be somewhat lower, if second hand units were to be installed.

Typical works cost of production of DRI is estimated at about Rs 1100 (US $ 85) per ton for coal-based units and Rs 1550 (US $ 119) per ton for a gas based unit. The higher works cost of gas-based units is due to the use of more expensive oxide feedstock (pellets) and also because of the higher natural gas price. The price of natural gas works out to about Rs 200 (US $ 15.5) per Gcal compared to Rs 70 (US $ 5.4) per Gcal for coal.

It would, therefore, be seen that while from the works cost point of view the coal-based processes are advantageous, the gas-based processes have an edge from the fixed charges viewpoint.

The DRI is sold in India at a price of about Rs 2450 (US $ 188.5) per ton ex-works, while the prevailing prices of heavy melting scrap is Rs 3800 (US $ 292)per ton.

Some observations

The Indian experience indicates that the coal-based direct reduction processes are highly sensitive to the characteristics of raw materials. The iron ores and coals available in different countries and even different plants in the same country vary widely in their characteristics. It is, therefore, necessary for each plant to suitably master the technology and adjust the operating parameters accordingly. This is corroborated by India's experience of the three different rotary kiln processes already in operation. The sizing of raw materials, removal of fines from the oxide feed and the method of introducing coal into the kiln are some of the major parameters to be controlled. The operating parameters and the temperature profiles have to be determined on the basis of the characteristics of the raw materials.

The operating experience of rotary kilns show that formation of accretions inside the kiln is unavoidable. However, it is possible to control the initiation and aggravation of the build-up through proper control of process parameters such as raw materials quality, maintaining appropriate temperature and air profiles, avoiding too many changes in a short time, monitoring the kiln conditions, preventive maintenance etc.

Since the operating technologies have to be mastered to suit the local conditions, it is desirable to install the equipment and machinery which have been already tried out on an industrial scale.

Under the present prevailing conditions in India, it is observed that the coal based DR plants are facing problems in obtaining regular supply of consistent quality coal. Moreover, in many cases, the quality of coal supplied to the plant is deteriorating. Therefore, not only the gestation period of the plants is high but the effective production capability is also getting adversely affected. The alternative of washing the coal, on the other hand, would result in increased input costs.

With regard to the gas-based plants, the availability of pellets is currently restricted to a single source. While the production capacity of the plants is not likely to be unfavourably influenced by the quality of input materials, the higher price of natural gas and oxide feed will have a detrimental effect on the economics of gas-based plants.

International acceptance of Indian expertise

It may be mentioned that the experience and expertise available in India is not limited to the few plants operating in India. Indian consulting engineers are internationally accepted for their expertise in direct reduction. They have been associated with the planning and installation of the direct reduction plants in Libya, Malaysia, Nigeria and Venezuela. Besides, they have carried out investigations on DR possibilities in a large number of countries of Asia, Africa and South America.

LIKELY FUTURE TREND IN INDIA

Recent forecasts indicate that the demand for carbon steels in India by the year 2000-2001 may correspond to about 29 million tons of crude steel. The estimated metallic input to produce the above amount of crude steel will be about 34 million tons. Against this requirement, the availability of hot metal and DRI from existing units and those under construction is expected to be 18 million tons. Considering the availability of domestic scrap and further allowing for the present level of 2 million tons of metallic imports, there will still be a gap of about 10 million tons of iron to be bridged by the year 2000.

The options available to bridge this wide gap need careful consideration, specially keeping in view the time horizon, availability of resources, the gestation period for creating new capacities etc. A part of the gap may be bridged through the expansion of the major existing integrated steel plants and that under construction, along the blast furnace route. The modernisation/expansion of existing electric arc furnace plants and those under construction may be associated with augmentation of DRI capacity. As regards new DRI capacity, there are possibilities of installing both gas-based and coal-based processes. For gas-based processes, the decisive factors would be the price of natural gas and the availability of pellets. For the coal-based processes on the other hand, the availability of coal of appropriate quality and sized ore of acceptable quality would be the major considerations.

The availability of DR quality iron ores (+ 65% Fe) in India is somewhat limited and the known occurrences of such ores are restricted to certain specific geographic regions. On the other hand, ores of +60% Fe quality is spread wider as well as there is a greater availability of non-coking coals with somewhat high ash content. These are not preferred for the production of DRI. Some of these raw materials may perhaps be acceptable to the smelt reduction processes. In the smelt reduction processes the gangue content of the ore and the ash in the coal are removed as slag. Besides, the molten metal available may be refined by the oxygen processes. This, in turn, obviates the use of large quantities of electric power for melting of metalic charge for production of steel. In this connection, it may perhaps be mentioned that a good many of the smelt reduction technologies are also based on the use of electric smelting processes which are power intensive.

India is considering various options and the developments in these emerging processes are being closely observed. Tests on Indian raw materials have been carried out with several processes such as Combismelt, Corex, Inmetco, Inred and Pelletech. While the preliminary results have indicated the potential of some of these processes, further investigations will be necessary to establish fully the acceptability of the Indian raw materials by these processes for obtaining consistent, reproducible results and for generating dependable data to appropriately project the techno-economics of a commercially viable unit.

SUGGESTIONS FOR THE ISLAMIC REPUBLIC OF IRAN

The Islamic Republic of Iran has large reserves of petroleum based fuels. The country had installed and successfully operated the first Purofer unit of direct reduction. Installation of plants based on other processes were also planned. Considering the vast reserves of natural gas, there is a possibility of setting up plants in Iran for the production of direct reduced iron both for domestic use and perhaps for export of direct reduced iron.

The Islamic Republic of Iran is also know to have coal deposits. The main coal bearing regions are:

- the Northern Elburz regions
- the Southern Elburz regions
- the Khorasan region
- the Kerman regions
- the Central region

Geologically, the coal formations in Iran belong to lower and middle Jurassic age, and no permo-carboniferous occurrences of coal have yet been found. The suitability of the coal for direct reduction purposes needs to be investigated.

While the country has adequate energy resources to install direct reduction plants, the question of suitable oxide feed needs careful consideration. The quality of oxide feed used for direct reduction is determined by the end use of the product. As a melting stock for steelmaking, it should be rich in iron content with low impurities and gangue content. Appropriate sources for obtaining such oxide feed stocks needs to be investigated. It may be mentioned that the gas-based shaft furnace processes require greater thermal stability of the oxide feed than the coal-based rotary kiln processes.

Installation of steelmaking capacities based on the direct reduction route requires large inputs of electric power. The availability of electric power would be a factor governing the selection of locations for the DR-EAF plants. While until recently the DR-EAF plants were considered reasonable solutions for producing non-flat products in midi-plants, recently with the development of thin slab casting, the installation of flat product plants based on DR-EAF appears to be economically viable. The first such plant is now under construction. Subject to the availability of adequate electric power, it is also possible to build large integrated DR-EAF complexes. A 4 million ton capacity based on DR-EAF route has been installed at SIDOR, Venezuela.

Concluding remarks

In conclusion, it may be said that the blast furnace has been reigning supreme for centuries in the global scenario because of its remarkable ability to accommodate itself to changing conditions and raw materials, as well as because of the refinements and efficiency brought about in the process itself and in the energy usage. The commercialised direct reduction and other emerging processes have, however, added a new dimension to ironmaking. Their very nature suggests that no one process is best for all applications and any particular process will become acceptable only under specific local conditions.

The scenario of the Indian Steel industry in the foreseeable future seems to suggest that while the blast furnace will continue to retain its predominant position as the foremost ironmaking technology, the alternative processes may also have a role to play. In the final analysis, however, only those alternative processes will come to stay which are appropriate to the local resources situation; which are capable of producing on a sustained basis consistent and predictable quality of iron acceptable for steelmaking or other end-uses; and which assure minimum possible energy consumption and are commercially viable.

The energy situation in Islamic Republic of Iran favours the possibility of adoption of direct reduction processes fairly extensively. The experience and expertise available with the Iranian Organisations and Indian consulting engineers could be shared with advantage in the planning and development of DR-based units in the Islamic Republic of Iran.

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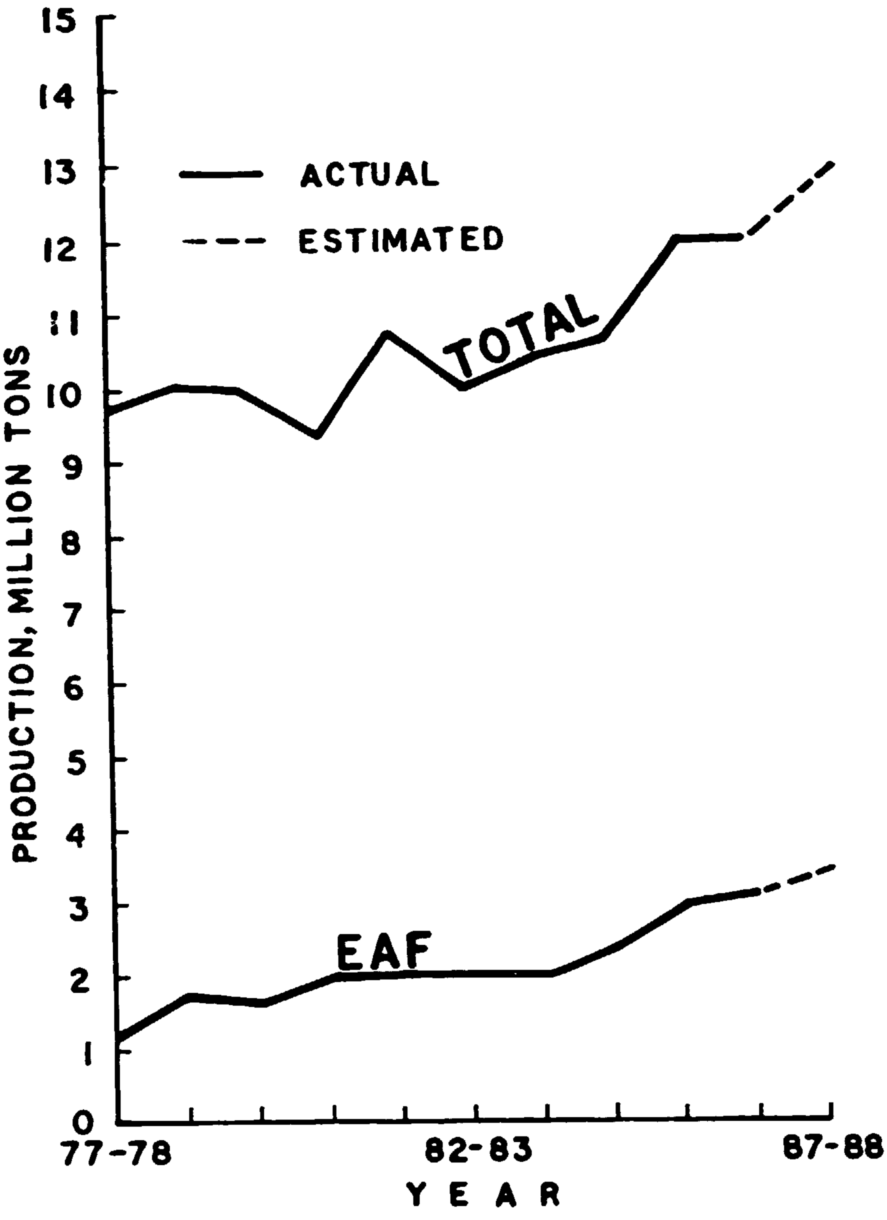

FIG. I - CRUDE STEEL PRODUCTION IN INDIA

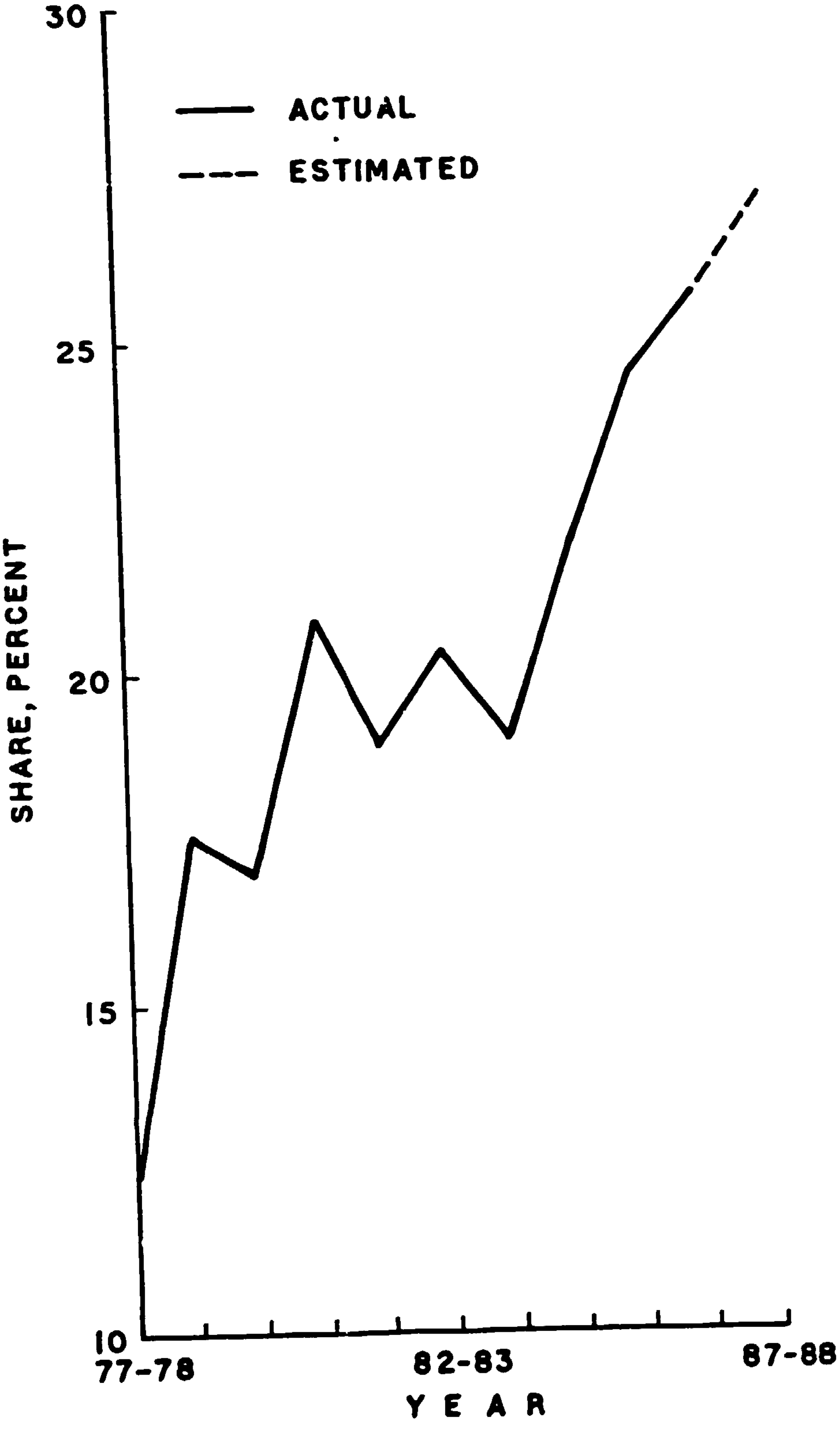

FIG. 2 – SHARE OF EAF STEEL IN TOTAL CRUDE STEEL PRODUCTION IN INDIA

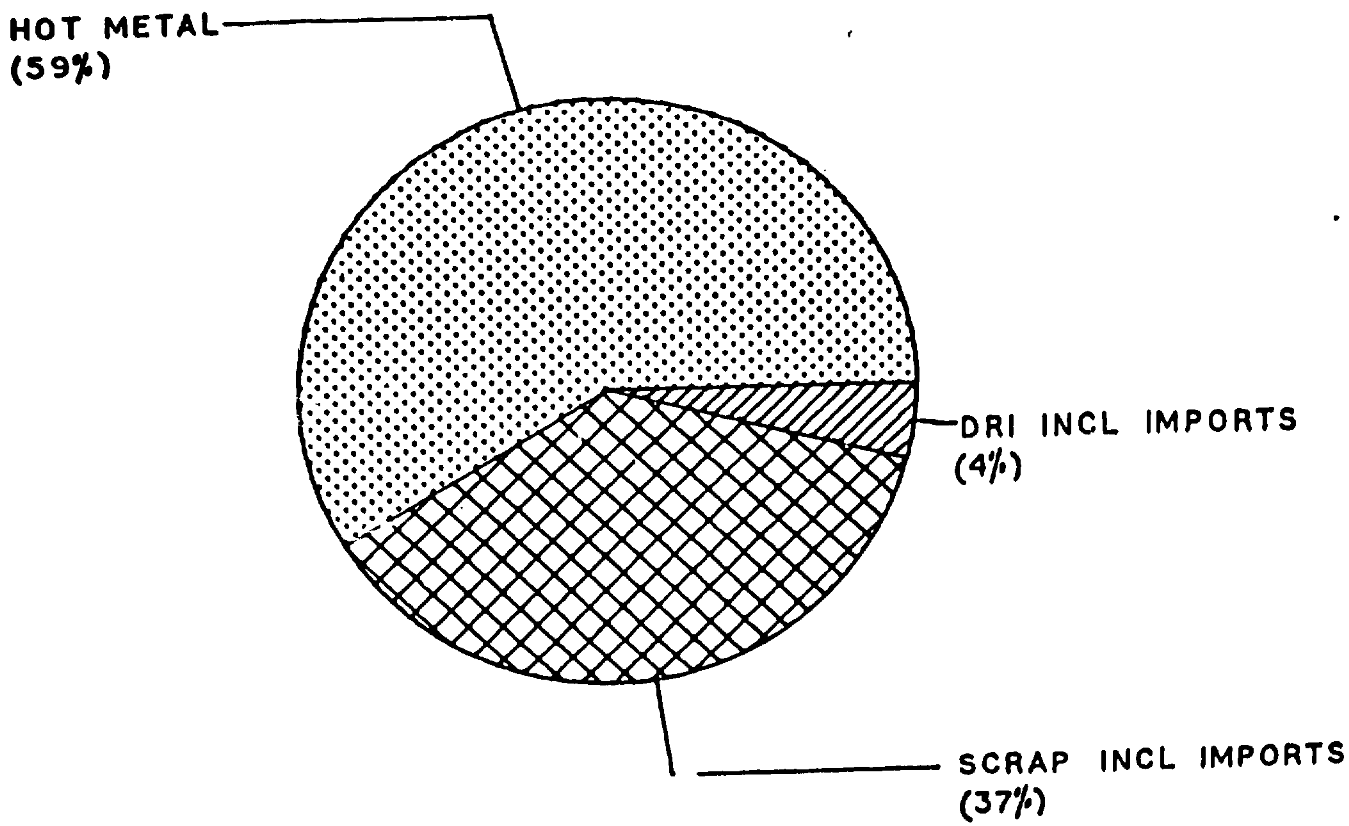

FIG. 3 — SHARE OF DIFFERENT FORMS OF METALLIC INPUT FOR CRUDE STEEL PRODUCTION IN INDIA IN 1986-87

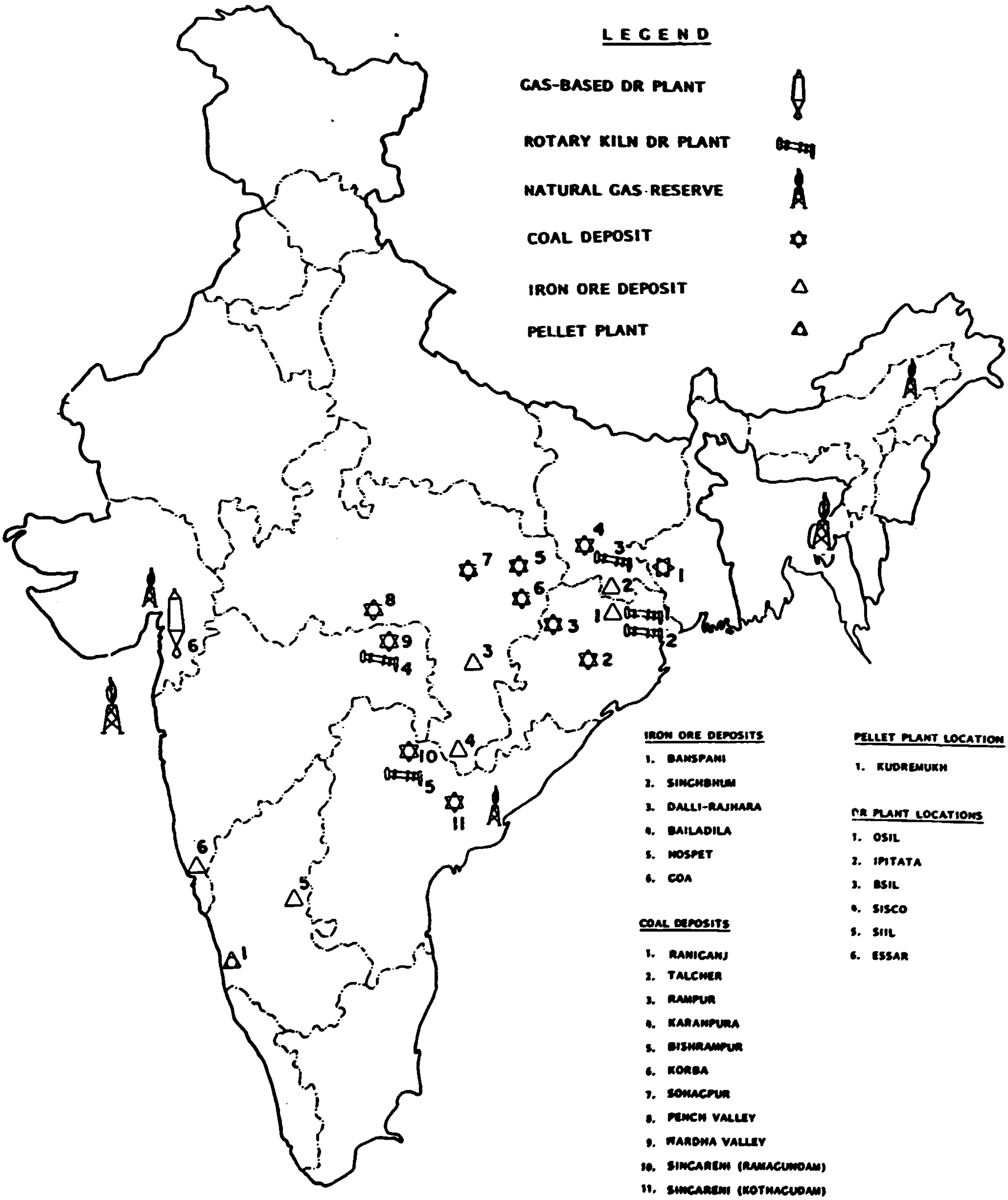

FIG. 4 - PROBABLE SOURCES OF RAW MATERIALS AND LOCATIONS OF DR PLANTS INSTALLED/UNDER CONSTRUCTION IN INDIA