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ON-SITE PROCESSING OF IRON ORE IN DEVELOPING COUNTRIES THROUGH THE STAGE OF PREREDUCED AGGLOMERATION[1]

by

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SUMMARY

The general consensus that raw-steel production will reach 1000 million tons worldwide between 1980 and 1985 implies the corollary that global iron-ore requirements will be of equal magnitude 3 to 5 years earlier. Both events will generate excellent opportunites in the 1980 decade for the developing countries to take part increasingly in the activities of the world's iron ore and steel industries.

This conclusion is supported by past developments and by recent trends that point to increased iron-ore mining and processing activity and also to extended on-site or near-site pretreatment and steel-producing operations in the developing countries. Some of the factors that support such developments are forecast in the paper, as follows:

1. Global raw-steel production is expected to increase to 915 million metric tons by 1980 and to 1025 million tons by 1985. The share of the developing countries will equal about 10% of the world-wide total in 1980 and nearly 12% in 1985.

2. Known iron-ore reserves in the world total approximately 300,000 million metric tons, and potential resources another 550,000 million tons. Exclusive of the Centrally Planned Economy countries, the developing countries account for about 40% of 185,000 million tons of iron-ore reserves.

3. Iron-ore production is likely to reach 1030 million tons in 1980 and 1250 million tons in 1985. Outputs in the developing countries are estimated at around 30%, about 310 million tons and 380 million tons for those years, respectively.

4. International iron-ore trade may rise to 420 million tons of crude ore in 1975 and 550 million tons by 1980.

5. Highly processed ores will continue to be in growing demand in the 1970's and 1980's. Globally, screened run-of-mine and direct-shipping ores are forecast to increase from 298 million tons in 1970 to 395 million tons in 1985, a decline of 8% to 31.6%;

sinter fines exports are expected to rise from 346 million tons in 1970 to 500 million tons in 1985, a drop of 6% to 40% of the total; oxide pellets estimates point to 231 million tons in 1985 from 106 million in 1970, a 4.4% advance to 18.5%. Prereduced pellet use will not become significant until 1980. The demand for directly-reduced products is foreseen as 64 million tons in 1980 and 124 million tons in 1985. Those tonnages equal 5.9% and 10%, respectively, of the iron-ore consumptions for those years.

6. Technology already exists to accomodate the anticipated prereduced tonnage demands. This, plus advances in conventional ore mining and processing techniques, can facilitate increased on-site ore pretreatment at new and existing iron-ore mines in developing countries.

7. Directly-reduced iron ore is well-suited for use in ironmaking and for steelmaking.

8. The technical and economic viability of direct-reduction processes based on gaseous reductant has already been demonstrated in commercial operations in the United States, Mexico, and West Germany.

9. There is a wide range of mutual benefits available to iron-ore mining and steel-plant interests in both developed and developing countries. The effective realization of such advantages depends on the establishment of joint cooperative programs and close harmonious relationships between representatives of the mining and steel companies, on the one hand, and the mineral resource countries on the other.

FORECASTS

Iron ore has become one of the most important commodities in international trade in the past decade. This development has been the result of a number of new factors that have emerged since 1950, among which the following have been significant:

- a growing demand for iron to satisfy the steelmaking needs of an expanding world economy;
- improved ironmaking and steelmaking practices leading to:
  a) increased consumption of iron-bearing ores and decreased dependence on scrap for steelmaking;
  b) wide use of highly beneficiated burdens for ironmaking;
  c) new ore-pretreatment techniques yielding high-quality ore products from low-grade run-of-mine ores;
- the opening of large iron deposits producing rich natural ores and/or high-grade concentrates in areas remote from iron consumption centers, and the development of low-cost ocean transportation methods to move large tonnages of such ore over long distances; and
- the emergence of Japan as the world's largest importer of iron ore.

The Changing Patterns of Iron Ore and Steel Industry

There is a sequential process line in the overall steel production operation that moves from iron ore to pig iron to raw steel to semi-finished and finished steel products. The pig iron/steel transformation is the most important, and approximately 120 years ago the invention of the Bessemer converter and the open-hearth steelmaking processes made steel production an economically viable mass industry. For nearly half a century Bessemer practice dominated the steel operation until, around 1905, it lost its leadership to the open-hearth method. Another 50 years later, a more rapid process, the oxygen-blown furnace, was introduced for large-scale production. It is now the most widely-used steelmaking practice of the industry.

Similar technical developments were introduced at all other stages of the steel operation. These included modifications in mining, concentration, transport, and use of iron ore for the more efficient manufacture of pig iron on the one side, and the more effective transformation of raw steel to semi-finished and finished products on the other. Together, these changes made possible the production of unprecedented magnitudes of steel tonnages, globally and in individual countries. They also generated needs for great quantities of the industries' two main materials -- iron ore and coking coal.

Table 1 illustrates that in 1970 world steel production equalled 592 million tons. Twenty years earlier, the United States accounted for more than half the 192 million-ton global output of raw steel; by 1955, its share of the world total had dropped to 39% and continued to decline to 20% by 1970. The 19% fall-off in the U. S. contrasted with only 2% in Western Europe, a balanced condition in Eastern Europe, and an impressive 12% advance in Japan from 4% in 1955 to 16% in 1970. Steel output in the developing areas, represented by all of Latin America, Africa, Australia, and "Others", increased from 12 million to 52 million metric tons, a combined rise of from 5% to 9% of the world total.

World steel production is expected to continue to grow, reaching 735 million tons in 1975, 915 million in 1980, and 1025 million tons in 1985. With these increases, the developing region tonnages will also advance, to totals of about 100 million tons and 130 million tons in 1980 and 1985, representing approximately 12% of the total output* of those years.

Iron Ore Resources

The most recent estimates of the world resources, published in 1970 (3), were completed in 1968. They reveal a fourfold increase over figures established only 15 years earlier. Economically available reserves equal 251,000 million tons and known potential ores about twice as great, distributed generally, as shown in Table 2. The known iron ores in the developing countries, the economically advanced nations, and the centrally planned economies equal 81 billion, 58 billion, and 112 billion metric tons, respectively. With the centrally planned areas' reserves excepted, the remaining 139 billion tons are divided 42% in emergent countries and 58% in developed ones.

The figures cited above are already recognized as being too low. Since they were published 3 years ago, the Australian reserves of 16 billion (10^9) tons have been augmented greatly, and the discovery of the Carajas deposits in northern Brazil adds at least 15 billion tons to the reserves total. Table 2 indicates a wide dispersion of iron ore endowments spread generally over the earth. Geologically, it is possible to draw a logical picture of iron deposit distribution that places metamorphosed Kombi-type ores in pre-Cambrian Shield areas; bedded oolite ores in sedimentary zones that date to periods later than pre-Cambrian; massive-type ore formations in the world's tectonically deformed regions; and laterites within a circular belt lying some 20 degrees on either side of the earth's equator. Within these four broadly described areas lie most of the world's land mass, and large resources of iron ore are therefore to be found on every continent. But the size and distribution of these deposits are random and unequal.

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* Latin America, Africa, and Others, as listed in Table 1.

(3) "Survey of World Iron Ore Resources", U.N. Doc. No. E.69.II.C.4; New York, 1970

TABLE 1

WORLD RAW STEEL PRODUCTION FORECASTS - 1975/1980/1985
BY SELECTED REGIONS AND COUNTRIES
(in Millions of Metric Tons & Percent)

	1970		1975		1980		1985	
	MT	%	MT	%	MT	%	MT	%
WORLD TOTAL	592.2	100.0	735	100.0	915	100.0	1025	100.0
North America	131.7	22.3	149	20.3	170	18.6	181	17.7
U.S.A.	120.2	20.3	135	18.3	154	16.8	163	15.9
Latin America	13.0	2.2	28	3.8	43	4.7	49	4.8
Argentina	1.8	.3	3	.3	5	.5	8	.8
Brazil	5.4	.9	11	1.5	18	2.0	22	2.1
Mexico	3.9	.7	6	.8	10	1.1	12	1.2
Venezuela	.9	.2	2	.3	3	.3	4	.4
Europe - West	161.1	27.2	174	23.7	219	23.9	243	23.7
E.E.C. & U.K.	137.1	23.2	140	19.1	168	18.4	167	16.3
Belgium-Luxem.	18.1	3.1	18	2.4	22	2.4	24	2.4
France	23.8	4.0	23	3.1	27	3.0	30	2.9
Germany (W)	45.0	7.6	49	6.7	60	6.5	65	6.4
Italy	17.3	2.9	16	2.2	19	2.1	22	2.1
Netherlands	5.0	.9	6	.8	7	.8	8	.8
U.K.	27.9	4.7	28	3.9	33	3.6	38	3.7
Austria	4.1	.7	5	.7	6	.6	7	.7
Spain	7.4	1.2	10	1.3	16	1.7	18	1.7
Sweden	5.5	.9	7	1.0	9	1.0	10	1.0
Europe - East	154.6	26.0	187	25.4	227	24.8	256	25.0
U.S.S.R.	115.0	19.4	135	18.4	160	17.5	178	17.4
Czechoslovakia	11.5	1.9	15	2.0	19	2.1	21	2.1
Germany (E)	5.4	.9	7	1.0	10	1.1	11	1.1
Poland	11.6	2.0	15	2.1	18	2.0	20	1.9
Rumania	6.4	1.1	10	1.3	12	1.3	13	1.3
Asia	119.6	20.2	169	23.0	212	23.2	241	23.5
Japan	93.3	15.8	135	18.4	166	18.1	176	17.3
China	17.0	2.9	22	3.0	25	2.7	35	3.4
India	6.3	1.1	8	1.1	15	1.6	18	1.7
Africa & Mideast	5.4	.9	9	1.2	13	1.4	18	1.7
Rep. of So. Africa	4.7	.8	8	1.1	10	1.1	14	1.4
Oceania	6.8	1.2	19	2.6	31	3.4	37	3.6
Australia	6.8	1.2	19	2.6	30	3.3	36	3.5

Source: 1970 - Stahl und Eisen; April 29, 1971; p 533
1975/1980/1985 - Estimates by J. R. Miller, 1971/1972

TABLE 2

ESTIMATES OF GLOBAL IRON ORE RESOURCES
(As of 1968; in Millions of Metric Tons)

Developed Areas

Country/Region	Reserves	Resources	Total
North America	43,900	186,900	230,800
U.S.A.	7,500	97,500	105,100
Canada	36,300(a)	89,400	125,700
Western Europe	20,100	12,300	32,400
EEC & UK	12,900	8,600	21,500
Sweden	3,400	-	3,400
Others	3,800	3,700	7,500
Eastern Europe	111,700	194,600	306,300
USSR	110,500	193,800	304,300
Others	1,200	800	2,000
Africa	2,800	5,100	7,900
Rep. of So. Africa	2,400	1,800	4,200
Rhodesia	400	3,300	3,700
Oceania	16,800	(b)	16,800
Australia	16,100	-	16,100
Others	700	-	700
DEVELOPED AREAS	81,000	201,300	282,300
DEVELOPING AREAS	58,000	135,300	193,900
CENTRALLY PLANNED AREAS	111,700	194,600	306,300
GLOBAL TOTAL	251,300	531,200	782,500

Developing Areas

Country/Region	Reserves	Resources	Total
Latin America	34,700	58,700	93,400
Brazil	29,400	9,600	39,000
Chile	600	1,300	1,900
Mexico	600	600	1,200
Peru	1,000	1,100	2,100
Venezuela	2,100	-	2,100
Others	1,000	46,100	47,100
Asia & Middle East	17,300	54,200	71,500
India	8,600	20,400	29,000
Indonesia	100	500	600
Mainland China	5,300	25,500	30,800
Philippines	900	2,200	3,100
Others	2,400	5,600	8,000
Africa	4,000	19,400	23,400
Algeria	600	1,000	1,600
Angola	200	1,100	1,300
Congo	100	5,100	5,200
Gabon	900	300	1,200
Ivory Coast	-	2,400	2,400
Liberia	700	-	700
Mauritania	100	400	500
Others	1,400	9,100	10,500

Source: United Nations, Survey of World Iron Ore Resources, Doc. No. E69.II.C.4; New York, 1970

(a) Includes 2,600 million tons of reserves and 3,000 million tons of resources in the West Indies
(b) "Vast" additional quantities not included

Iron-Ore Production

The extent to which any ore resource is developed does not necessarily have any consistent relationship to the size of the deposits. In recent years, however, output levels at individual mines have gone up dramatically and the number of active mines has increased greatly. As late as 1955, the global production of 514 million tons of iron ore came from some 45 countries, but only 10 of these - Brazil, Chile, Peru, and Venezuela in Latin America, Liberia and Sierre Leone in Africa, Finland and Sweden in Europe, Canada, and India - were important producers of high-grade iron ore, mainly for export. In 1970, the number of such iron-ore shippers is nearly twice as great.

The increase in global production of iron ore, which in 1970 reached 753 million tons, was made possible by the expansion of old mines and the development of new sources of iron-bearing minerals. Many major projects, completed since 1955, that added large new iron-ore producing and processing capabilities throughout the world, were based on long-term contracts with ore consumers in Japan, the United States, and Europe. In other cases, steel producers participated in the exploration of deposits and the subsequent opening of mines and facilities in Canada, the U. S., Asia, South America, and Africa. In both instances, there has been some provision of assured markets for a substantial part of the additional iron ore production.

The records of iron ore and iron-ore derivative production for 1955 and 1970 are shown in Table 3. The forecasts of the global ore requirements during the 1970's suggest production levels of about 910 million tons (510 million tons fo Fe) of crude ore in 1975 and 1000 million tons (625 million tons Fe) in 1980.(4) In the future, practically all the ores mined will be screened and increasing amounts—approximately 75% of the mined output in 1980 compared to 67% in 1970—beneficiated or pretreated at or near the mine site.(5)

The 1970 iron-ore production capability indicated in Table 3 has been confirmed within acceptable limits by the approximate concurrence with the 1970 output record; the 1975 capacity anticipations take into account many mine and process facility programs that are already committed. Both estimates point to the likelihood that new mining and treatment installations for some 350 million tons of iron ore annually will be built by 1980.(6) Approximately one-third of this added capacity will be achieved by modernizing and replacing old units; one-third by enlarging existing facilities; and one-third by wholly new installations at new mine sites.

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(4) "The Inevitability of Prereduction in Iron and Steelmaking"; by J.R. Miller; American Chemical Society, Annual National Meeting; Boston; April 1972

(5) "Iron Ore Mining and Pretreatment in the World and Latin America During the 1970-1980 Decade"; by J.R. Miller; 10th ILAFA Congress; Caracas; Aug. 1970

(6) UNCTAD Doc. TAD/INT/SEM.1/7; "The Implications of One Billion Tons of Iron Ore a Year"; by J.R. Miller; Symposium on Planning of the Foreign Trade Sector; Sept. 1970; Geneva

TABLE 3

GLOBAL PRODUCTION OF IRON ORE: 1955 & 1970
AND PROJECTED PRODUCTION CAPACITY: 1970 & 1975
(In Millions of Metric Tons)

Country/Region	Actual Production				Estimated Capacity			
	1955(1)		1970 (2)		1970(3)		1975(4)	
	Tons	%	Tons	%	Tons	%	Tons	%
GLOBAL TOTAL	372	100	753	100	765	100	925	100
North America	121	32	136	18	144	19	172	19
U.S.A.	105	28	90	12	96	13	102	11
Canada	16	4	46	6	48	6	70	8
West Europe	118	32	133	18	144	19	141	15
EEC & UK	91	25	83	11	90	12	80	9
Others	27	7	50	7	54	7	61	6
Eastern Europe	79	21	210	28	204	27	233	25
USSR	72	19	195	25	188	25	213	23
Others	7	2	15	2	16	2	18	2
Asia	21	6	88	12	88	11	110	12
India	6	2	29	4	31	4	44	5
Mainland China	9	2	52	7	40	5	44	5
Others	6	2	8	1	17	2	22	2
Latin America	17	5	76	10	80	10	114	12
Africa	12	3	62	8	60	8	65	7
Australia	4	1	46	6	45	6	90	10

Source: (1) U.S. Bureau of Mines; (2) Stahl und Eisen, 18 March 1971; (3) Approximate Estimates, based on reported projects and Annual Review, Mining Journal, London, June 1970; (4) Estimated by Author 1966 and modified in 1968 and 1971.

In 1970, iron-ore production in the centrally planned countries equalled 200 million tons. The developing countries accounted for [illegible] tons, or [illegible] of the global total. An increase of about [illegible] in global iron-ore mining facilities is anticipated by 1975. Forecasts for iron ore production and consumption through 1985 are shown in Tables 4 and 5. On a global scale, the estimates point to 910 million tons of ore averaging 56.[illegible] Fe in 1975; 1080 million tons with 57.7% iron content on the average in 1980; and 1250 million tons containing 740 million tons of iron (Fe=59.2%, overall) for 1985. The developing regions, which are expected to produced 250 million, 310 million, and 380 million tons of iron ore in 1975, 1980, and 1985, respectively (27.4%, 29%, and 31%), are foreseen as consuming 90 million, 120 million, and 160 million tons in those years (9.9%, 11.1%, and 12.8%).

Iron-Ore Trade

International trade in iron ore in 1970 equalled 251 million tons, representing 33% of the total world output, as shown in Table 6. A United Nations study (7) observes that, "International trade in iron ore amounted to about 150 million tons in actual tonnage in 1960, or about 30% of the world output. In 1968 it had increased to 250 million tons or 40% . . ." and adds, " . . . the increase in international iron ore trade should continue throughout the next decade. Expressed in terms of iron content, it might exceed 200 million tons in 1980". Under certain conditions, iron-ore trade "could reach 250 million tons in 1975 and around 350 million tons in 1980". (8)

The pattern of world trade in ore and ore derivatives is detailed in Table 6. The principal flows in 1970 were: (a) from Canada and South America to the United States; (b) from Scandinavia, Africa, and South America to Western Europe; (c) from the USSR to the East European countries; and (d) from Australia, Asia, and South America to Japan. The large "open" market that emerges is primarily Western Europe and, to a much smaller degree, the U.S. and Japan (because both are already well covered by part-ownership or long-term arrangements). However, the magnitude of their needs and the requirements of the EEC and UK steel-makers have already stimulated strong competition among the ore-producing companies of Australia, Latin America, South and West Africa.

The USSR may be expected to meet its own requirements and a large part of East European ore needs. Relatively small shipments from the Soviet Union to the UK have been made since 1969; efforts to increase such trade may meet some resistance, now that Great Britain has entered the European Common Market. An increasing amount of the ore consumed in Eastern Europe (other than the USSR) is likely to come from India, Africa, and South America by 1980.

Japan will continue to be the main factor in the world iron-ore market, following a deliberate policy of import from many sources. A flexible procurement program calls for obtaining approximately one-third of its ore needs from Australia, one-third from South America and India, and the balance from North America, Africa, and Southeast Asia.

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(7) "The Iron Ore Market," by A. Marelle; U.N. Doc. TAD/INT/SEM.1/1; July 1970; for Interregional Seminar on the planning of the Foreign Trade Sector; Geneva, Oct. 1970

(8) 250 million and 350 million tons of contained iron would equal about 420 million and 550 million tons of crude ore, for average Fe contents of approximately 60% and 62%, respectively.

ESTIMATED IRON ORE PRODUCTION: 1975/1980/1985

(In Millions of Metric Tons)

Region	1975 Iron Ore	1975 Iron-in-Ore	1975 % Fe(3)	1980 Iron Ore	1980 Iron-in-Ore	1980 % Fe	1985 Iron Ore	1985 Iron-in-Ore	1985 % Fe
WORLD	910	510	56.2	1080	623	57.7	1250	730	58.2
North America	162	102	61.7	183	115	62.8	225	[illegible]	[illegible]
USA	102	63	60.3	108	67	62.0	127	79	[illegible]
Canada	60	39	63.5	75	48	63.7	98	62	65.3
Latin America	118	74	62.6	153	96	63.8	190	123	65.0
Brazil	62	40	64.7	78	50	64.3	105	70	[illegible]
Chile	14	8	53.6	16	10	62.5	18	12	65.0
Peru	13	7	54.5	16	9	58.3	20	13	[illegible]
Venezuela	24	16	66.0	30	20	65.3	42	27	[illegible]
Europe - West	121	49	40.2	112	52	46.3	105	53	50.6
France	42	13	30.5	35	11	31.0	33	[illegible]	34.4
Sweden	37	23	62.8	44	29	65.7	52	34	65.0
Europe - East	300	164	54.8	382	215	56.3	430	245	57.2
USSR	290	157	54.[illegible]	350	197	56.2	395	[illegible]	[illegible]
Africa	85	52	61.2	95	58	61.0	115	69	60.0
West (1)	55	33	60.5	63	37	59.0	79	[illegible]	[illegible]
South (2)	18	11	62.5	21	12	56.7	24	15	[illegible]
Asia	66	37	55.5	82	48	58.2	93	57	60.7
India	50	30	59.3	64	38	59.3	75	46	[illegible]
Oceania	58	38	66.5	75	45	63.5	92	58	63.5
Australia	55	35	65.0	70	44	63.3	83	52	53.[illegible]

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(1) "West Africa" includes Gabon, Mauritania, Liberia, and Sierra Leone in this table.
(2) "South Africa" includes Angola and the Republic of South Africa in this table.
(3) Iron contents figures have been rounded, with resulting inaccuracies possible.

TABLE 5

WORLD-WIDE IRON ORE CONSUMPTION FORECASTS BY REGIONS: 1975 - 1980 - 1985

(in Millions of Metric Tons)

Region	1975 Steel Prod.	1975 Pig Iron Needed	1975 IronOre for P.I.	1975 TOTAL ORE	1980 Steel Prod.	1980 Pig Iron Needed	1980 IronOre for P.I.	1980 TOTAL ORE	1985 Steel Prod.	1985 Pig Iron Needed	1985 IronOre for P.I.	1985 TOTAL ORE
WORLD	735	504	655	910	910	637	1020	1080	1025	[illegible]	[illegible]	[illegible]
North America U S A	140 135	99 69	169 131	181 163	170 154	114 102	183 163	194 175	[illegible] [illegible]	121 [illegible]	[illegible] [illegible]	[illegible] [illegible]
Latin America	28	19	38	40	43	29	46	50	49	32	52	55
Europe - West E E C & U K	174 140	118 99	205 172	212 178	219 166	151 119	242 190	255 200	243 157	167 133	[illegible] [illegible]	[illegible] [illegible]
Europe - East U S S R	187 135	131 97	222 165	238 177	227 180	162 115	260 184	275 194	255 [illegible]	[illegible] [illegible]	[illegible]	316 220
Asia Japan	169 135	117 92	184 145	193 155	212 166	148 113	236 181	250 192	[illegible] 170	[illegible] 121	273 [illegible]	[illegible] [illegible]
Africa & MidEast	9	6	12	13	13	10	16	17	18	13	[illegible]	23
Oceania	19	14	26	28	31	23	37	39	37	27	[illegible]	47

TABLE 6

PATTERNS OF GLOBAL TRADE IN IRON ORE, CONCENTRATES, AND AGGLOMERATES: 1970
(In Millions of Metric Tons)

	Production and Exports by Country or Area of Origin				Exports by Country or Area of Destination				
	Production	Consumption	Imports	Exports	United States	Canada	EEC + UK	Other Eastern Europe	Japan
United States	91	134	46	3	--	--	--	--	3
Canada	48	9	--	39	26	--	11	--	2
EEC + UK	83	162	79	--**	--	--	--	--	--
Other Western Europe	32	10	--	22	--	--	21	1	--
USSR	196	161	--	35	--	--	2	32	1
Other Eastern Europe	12	52	40	--	--	--	--	--	--
Japan	2	88	86	--	--	--	--	--	--
India	31	13	--	18	--	--	1	3	14
Other Asia*	6	2	--	6	--	--	--	--	6
Africa	58	24	--	34	2	--	22	1	9
Australia	51	19	--	32	--	--	3	--	29
South America	73	11	--	62	18	--	19	3	22
GLOBAL TOTAL	685*	685*	251	251	46	--	79	40	86

Source: Data from Stahl und Eisen, 18 March 1971; p. 3-5

* Includes Mainland China and North Korea (equal respectively to 45 million and 8 million tons).

** Includes certain intra-group shipments estimated at approximately 17 million tons.

TECHNICAL CONSIDERATIONS

The programs undertaken to expand iron-ore production capabilities from the present global capacity of about 800 million tons to 925 million tons by 1975, as indicated in Table 5, and to approximately 1,250 million tons to meet the requirements of the steel-production forecasts for 1985, have been greatly facilitated by many new technical developments. These include important process improvements and innovations before and after the iron mining operation. In this section, some of the more significant of such technical developments are briefly discussed, with emphasis on any possible impact they may have in developing countries with important mineral resource endowments.

Mineral Exploration

Recent improvements in mineral exploration methods include among other things, the following: (a) Aerial photographic techniques that make use of artificial satellites to scan very large areas. Individual techniques vary, but most use multifilter photography and analysis of reflection spectra. (b) Refinement of geophysical instruments that have increased capability to penetrate thick vegetable cover and deep overburdens. (c) Novel geochemical methods to detect buried mineral deposits. (d) High-speed computers for field data interpretation. This permits simultaneous analysis of data from several channels from a variety of geophysical instruments to facilitate the choice of potential exploration targets.

Although sponsored mainly by companies based in developed countries, these technical innovations are frequently used in the developing areas, as evidenced in a large number of recent United Nations and multicompany exploration programs.

Mining and Haulage

In the modern iron-ore industry, mining is predominantly by open-pit methods, although underground mining is still practised in older deposits and in special situations. Technical improvements have been introduced for both methods of operation. More efficient blasting techniques have been developed through the more extensive use of ammonium nitride/fuel oil (ANFO) mixtures, and other slurry explosives. Computer programs are in wide use to coordinate mining schedules and optimise extraction rates.

In underground mines, emphasis has been placed on underground haulage by tire vehicles rather than rail, and on underground crushing and screening plants so that ore transport is facilitated. In open-pit mines trucks are used extensively. A definite trend towards bigger equipment is clearly evident: 100 to 150-ton trucks are currently in use and larger units are planned and on order.

Impressive developments have taken place in long-distance transport methods, such as ocean-going vessels of 250,000 tons capacity and more for iron-ore shipment, and the use of pipelines for iron-ore slurry transport.

The latter technique has been in successful operation for nearly 5 years to move ore from the Sevage River Mine in Tasmania to a pelletizing plant at Port Latta, approximately 50 miles away. Widespread interest has been shown in the Marconaflo method of loading, conveying, and unloading iron-ore concentrates in slurry form. The system uses high-pressure nozzles to produce high-density ore slurries that may be moved in pipelines over land or loaded into ore vessels. More conventional developments include the use of belt conveyors for long-distance ore transport, including regenerative systems that take advantage of large vertical displacements to generate power, like the 10km conveyor moving bauxite in Weipa, Australia.

Iron-Ore Beneficiation

Beneficiation techniques are standard practice at all iron mining operations. These range from simple treatments such as crushing, screening, or blending to produce a desired direct-shipping ore, to complex agglomeration and prereduction techniques. Primary size reduction and classification methods have remained essentially unchanged, but significant innovations have been made in the more advanced ore-processing stages.

Ore crushing is an integral part of ore-preparation plants. Crushing operations serve a dual function: they reduce ore size to marketable limits, and they liberate coarse undesirable gangue constituents that may be in the ore. Size classification by screening follows crushing to separate the ore into specified size fractions. The ores are often blended also, to produce uniform product grades and to eliminate fluctuations in the chemical and physical characteristics of the ore that could cause problems during concentration.

Iron Ore Concentration

Physical concentration of iron ore usually involves procedures based on gravity, magnetic, and flotation methods of separation, singly or in combination. Ores whose gangue separates in the coarser sizes may often benefit from gravity treatment (Humphrey spirals) or low-intensity magnetic concentration (belts or drums). When the impurities are finely disseminated, fine grinding is usually necessary for mineral liberation, followed by magnetic or flotation treatment. Rod mills and ball mills are usually used for coarse grinding, but the modern trend is to use ball mills for very fine grinding. In recent years, autogenous grinding in which the ore itself becomes the grinding medium has been used more and more frequently.

The technology of iron-ore concentration has remained essentially unchanged for "ordinary" applications, during the past 20 years. A number of challenging problems remain, especially in the area of fine-particle separation for friable ores. In general, the major improvements in iron ore concentrating techniques have been directed at raising operating efficiencies and yields, so that processing costs may be reduced.

Iron-Ore Agglomeration

No aspect of iron-ore beneficiation has received more attention or progressed as much as agglomeration. Within the last 15 years, sintering and pelletizing have been developed to the point that measurement of certain physical characteristics in a laboratory can often be used to predict accurately the behavior of ores in commercial plants. Recent insights on the mechanisms of iron-ore agglomeration now permit process design modifications that formerly required lengthy experimentation under full-scale plant operating conditions.

Sintering

The sintering process is based upon the combustion of carbon intimately mixed with iron-ore fines and iron-bearing dusts under controlled conditions, such that incipient fusion of the mixture is achieved. In modern practice, the raw-material mix for the sintering process usually includes dolomite or limestone so as to produce self-fluxing and/or super-fluxing sinters. Basic sinters differ from acid sinters (those with no fluxes added) mainly in the nature of the sinter bond, which in fluxed sinters consists primarily of highly reducible calcium or magnesio-ferrites. In the case of acid sinters the bonding mechanism is primarily one of fused iron-oxide bridges. Typically, sinter is produced from mixes of such "waste" materials as blast-furnace dust, mill scale, and sinter fines, with additions of fluxes and coke breeze. Sintering machines may be batch-type units or continuous (Dwight-Lloyd) installations. The latter, which are very widely used, are usually of large capacity, with grate areas up to 10,000 square feet.

On a sintering grate, the sinter bed is first ignited and then brought to incipient fusion as a flame moves through the sinter-mix. Advance of the flame and fusion of the material within the bed are controlled by the flow of air through the grate and a system of wind-boxes. The final stages of the process include partial cooling of the sinter which is generally followed by crushing and screening. The "return" fines (normally minus 3/8-inch material) from this last operation are circulated back into the sintering grate for reprocessing.

The acceptance of the sintering process by the ironmakers can be traced to economic factors in blast-furnace productivity. Iron-ore sinters, particularly the self-fluxing and super-fluxing varieties, provide the ironmaker with iron burdens of consistent high quality in terms of reducibility and physical properties. Unlike unprocessed ores, sinter size can be closely controlled at the plant to meet the specific needs of blast-furnace operators. The increased use of sinters in Japanese and European furnaces has been effective in raising blast furnace productivity and lowering coke rates. Homogeneous and closely-sized sinters have made possible the use of higher driving rates with stable furnace operation.

The adoption of sinter practice and its pattern of development has been quite different in various areas of the world. Figure I illustrates the growth patterns of sinters, pellets, and ores in several regions of the world It is clear that sinter consumption predominates in Eastern and Western Europe,

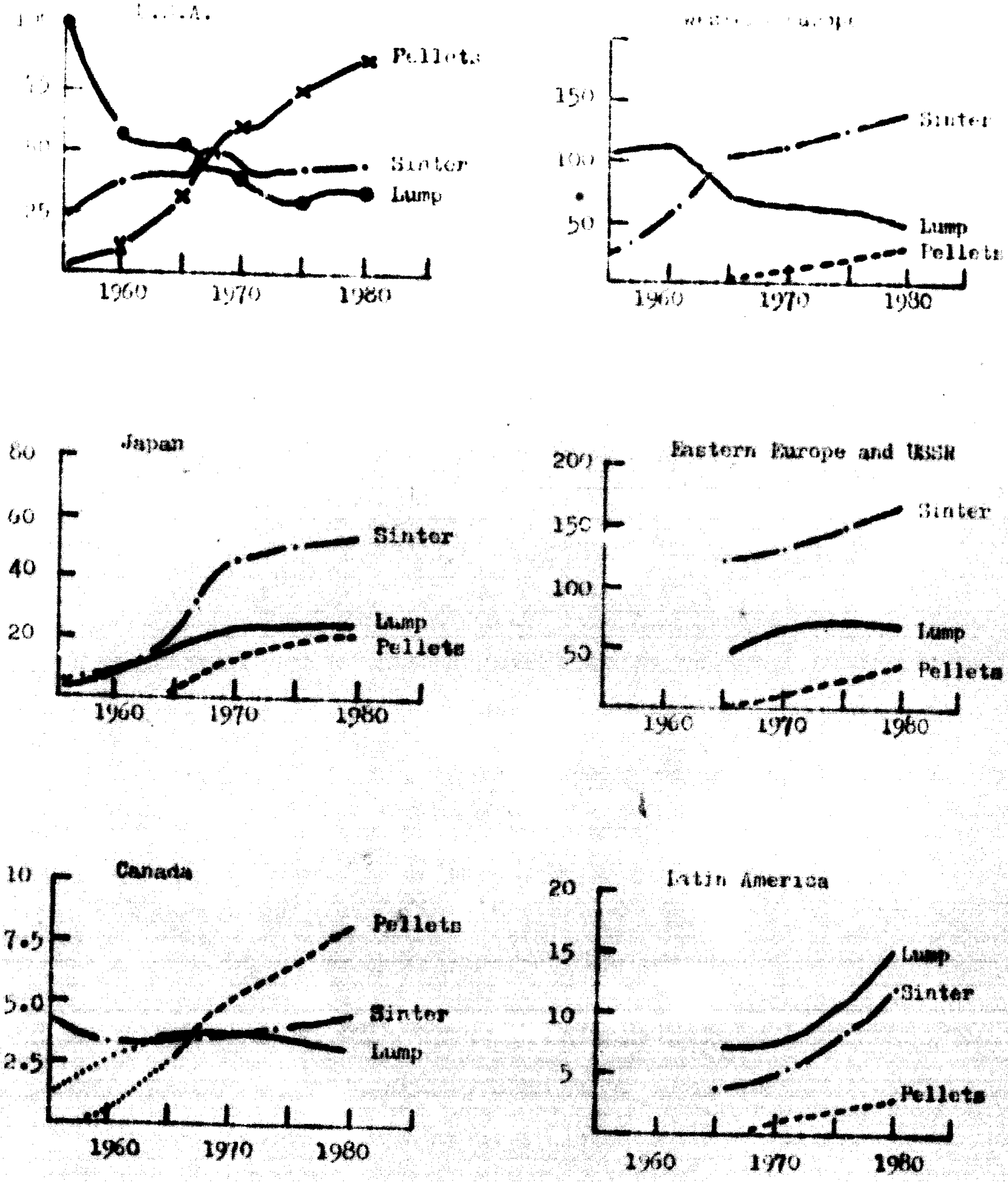

Figure I – Projection of iron-ore consumption tonnages by physical form (in million metric tons) the in Japan. In the United States and Canada, the pattern was similar until the early 1960's, when pellets became the preferred iron burden material. In Latin America, lump ores are still the principal burden material, but sinter consumption already shows a strong growth that is not greatly behind that of lump-ore consumption.

Pelletizing

Pelletizing is the operation by which hard semi-spherical agglomerates are made from finely divided materials. The process consists of two principal steps: balling and induration. The former refers to the operation of forming "green" (unindurated) pellets, which is normally done in rotating disks, drums, or cones. Induration refers to any means by which strength is added to the green balls so that they may withstand handling and transport without excessive physical degradation.

In general, iron-ore pellets are expected to have certain physical and chemical characteristics that make them suitable for blast-furnace use. The most common properties required of iron pellets are: (a) close size distribution, normally between 1/4 and 5/8-inch, to permit adequate permeability in the blast-furnace burden; (b) uniform chemical composition, rich in iron, and adequately reducible under high-temperature conditions; (c) mechanical strength to resist handling and transportation; and (d) good resistance to degradation under high temperatures in a reducing atmosphere.

The most recent technical innovations made in the field of agglomeration involve pelletizing. Because pelletizing, unlike sintering, can be and normally is done close to the mine, a discussion of modern technology in this field is particularly relevant.

Balling circuits in modern practice consist of essentially three operations: grinding, pellet rolling, and size classification. These operations differ according to the type of equipment used. Thus, balling drums require separate screening facilities to recirculate undersized pellets back into the balling circuit, while pelletizing disks size green pellets during the balling action and independent screening facilities are not needed, normally.

The idea that pelletizing requires extremely fine size distributions (60 to 80 percent minus 325 mesh) is being replaced by careful control of size distribution in the coarser sizes. Studies made nearly 10 years ago have indicated that acceptable pellets may be obtained with mixed ores containing as little as 27.8% of -150 mesh particles and that the ratio of coarse to fine fractions may be more important than surface area characteristics alone. (9)(10)

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(9) K. Smicek and J. Kandl: Hutnicke Listý 17 (11), 1962; pp 761/766

(10) P.A. Young: Iron and Steel, 38, (10), 1965; pp 455/462

An important area of inquiry that has been subjected to much study covers the use of binders. This has led to a trend toward replacement, wherever possible, of bentonite by inexpensive limestone and hydrated lime binders that can increase the basicity of the final pellet. In some cases, iron ore blending has been suggested as a substitute for bentonite addition.(11)

Induration of pellets is usually achieved in commercial operations by heat in vertical shaft furnaces, horizontal grates, or in grate-kiln combinations. In all of these, the induration process involves drying of the green pellets, heating to create iron oxide and/or a slag bond formation between the grains, followed by regulated cooling of the product. Control of the drying and heating cycles is important to maintain product quality and avoid such problems as spalling, premature pellet breakage, and cluster formation.

Recent innovations in hot induration processes include the development of the circular-grate pelletizing system, which is reported to have lower BTU requirements than conventional systems. Most of the advances made in the field, however, concern a better understanding of process parameters and their influence on product quality. Earlier problems concerned with pellet swelling and insufficient strength are now largely eliminated by improved induration cycle designs.

One of the interesting developments in recent years has been the introduction of cold induration processes. These can assume particular importance for the developing countries because (a) they reportedly require less capital investment and (b) they may be designed economically for smaller production capacities. Claims have been made (12)(13) that cold indurated pellets can exceed the physical specification of conventional acid pellets. The best known of the new processes is the Swedish Grancold Process, which utilizes about 10% portland or other cements (pozzolanic or slag cements) in the pelletizing mixture before balling. The green balls are subsequently coated with iron concentrate to prevent cluster formation, and are allowed to harden and cure for periods up to 4 weeks. Blast-furnace test results on these pellets have been reported to be quite favorable.

Other developments in cold induration processes include the carbonate bond process, the corrosion-bond process, and autoclave bonding with tars and pitches. In the carbonate bond process, (14)(15) the iron concentrate is mixed with approximately 7% lime prior to balling, and the green pellets are then partially dried and allowed to harden at 250° to 300°F in a CO_2 atmosphere under pressure. In the corrosion bonding method, iron chips and sodium chloride (NaCl) are incorporated into the pelletizing mixture which hardens as a result of corrosion products. (16)(17)

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(11) K. Meyer: Stahl und Eisen, 83 (22), 1963; pp 1337/1348
(12) R.K. Linder, et al: Grängesberg Ore News; Dec. 1970
(13) J. Svensson: Trans. Soc. Mining Engineers, AIME, 247, (1) 1970; pp 26/31
(14) M.C. Chang: AIChE and Mexican Chem. Engs. Joint Meeting;Denver Aug/Sept. 1970
(15) G.V. Gubin and L.M Taylev: Trudy Inst. Met., A.A. Baikova, 3, 1958; pp 63/68
(16) M.C. Chang: Mining Engng, 1966; pp 103/105
(17) A.N. Pokhvisnev, et al: Izvest. VUZ-Chern. Met. 8, (3), 1965; pp 29/35

Consumption Patterns and Forecasts of Iron-Ore Consumption

Although the growth in oxide pellet consumption has been rapid in recent years, the advance from 36 million tons worldwide in 1964 to 106 million tons in 1970 has only kept pace with the increase in the use of sinter, in terms of tonnage. Considering that pellet use is very heavily favored in the United States, a general preference is indicated for sinter in most other areas of the steelmaking world. An important reason for this is that pellets are usually produced near the source and sinter can be made at the plant. In terms of cash flows generated, sinter production permits a much larger part of the added values to be credited to the country where the ore is processed into iron and steel than does pellet manufacture. This extra benefit usually favors the iron and steelmaker who therefore has a good reason for bias toward the use of sinter over pellets.

This is particularly the case because most blast-furnace operators consider both agglomerates equally good as a charge material. The choice of sinter or pellets as a burden material is usually one of personal preference, within constraints over which the operator has little control. For example, U. S. companies are "locked into" pellet practice and most European plants are tied to sinter technique because the first have huge direct or indirect investments in major mining operations that include efficient pelletization installations, and many of the European companies have erected large well functioning sinter plants as part of their steelworks.

The future is therefore not likely to see any great shift from sinter to pellet practice or the reverse. The tonnages consumed in the global steel industry will increase for both agglomerates. Because larger amounts of iron ores will originate in an international market in the coming years, and because pellets ship and "handle" better than sinter and sinter fines, it is likely that the increment of pellets' tonnage used in the 1980's will be no less than that of sinter consumption. Expressed in percent, this will result in a rise in the proportion of pellet use. But the relative increase will probably come at the expense of run-of-mine ore as much as from decreased sinter usage. The tonnages forecast for this development are indicated in Table 7.

The global output of 106 million tons of oxide pellets in 1970 engaged the productive capacity of 138 million tons (18) available that year, at a utilization factor of 77%. The most recent tabulation (18) of pelletization capacity that will be in operation in 1975 lists a worldwide capability, based on scheduled construction and existing facilities, totalling 210 million tons; at 79% capacity operation that will produce the 165 million tons of pellets forecast for 1975. The new capacity scheduled for completion by the end of 1975 totals 62 million tons. Approximately 38% of the new pelletization capability is being erected in developing areas—2 million tons in Argentina, 8 million tons in Brazil, 6 million tons in Chile, 5 million tons in Mexico, and 2 million tons in Portugal; one must be struck by the high representation of Latin America in this list.

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(18) "World Iron Ore Pellet and Direct Iron Capacity", U.S. Dept. of Commerce; Feb. 1973

TABLE 7

PHYSICAL FORM OF IRON ORE CONSUMED IN THE WORLD - 1970 and ESTIMATES FOR 1975/1980/1985 (In Millions of Metric Tons and Percent)

Form	1970		1975		1980		1985	
	Tons	%	Tons	%	Tons	%	Tons	%
Screened ROM and Direct Charge Ore	298	39.5	332	36.3	357	33.1	395	31.6
Sinter Fines	346	46.0	402	44.3	463	42.8	500	40.0
Oxide Pellets	106	14.1	165	18.2	196	18.2	231	18.5
Prereduced Ore	3	.4	11	1.2	64	5.9	124	9.9
TOTAL	753	100%	910	100%	1080	100%	1250	100%

Prereduction

Table 7 includes estimates for the consumption of prereduced iron ore that increases from 3 million tons in 1970 to over 60 million tons or 5.9% of the global iron ore consumption anticipated in 1980, and to 124 million tons which represents 9.9% of the world total foreseen in 1985.(19) Presently, in the summer of 1973, there are no less than 10 plants in operation in 6 countries and 9 others on start-up. The facilities of the first group are located in Mexico, the United States, the Republic of South Africa, Greece, F.R.Germany, and New Zealand (20); in the second set are plants in Brazil, Venezuela, Canada, Mexico, South Africa, the United States, Italy, and Japan. Together, these account for 19 direct-reduction operations in 11 countries; their combined capacity is given as 5.6 million tons a year, as shown in Table 8.

Table 8 does not include at least 2 new important projects for which contracts were signed, according to announcements made early this year: a 400,000-ton FIOR plant in Venezuela with provision for prompt expansion to 1.2 million tons a year capacity, and a 5 million-ton Korf-Midrex installation in the USSR. The latter project is apparently subject to confirmation, depending

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(19) These forecasts have been stated at industry meetings since 1969. Concerning the projections, the author has said: "My estimate that worldwide demand and consumption of directly-reduced iron ore will reach 11 million tons by 1975 is widely judged to be reasonably acceptable, but increases to 64 million tons 5 years later and to 124 million tons by 1985 are much harder to take." ("The Inevitable Magnitudes of Metallized Iron Ore", Annual Convention of the Ass'n of Iron & Steel Engineers; Pittsburgh; Sept. 1972.)

(20) The "older" Wiberg and Höganäs installations in 4 plants in Sweden with capacity to produce 130,000 tons per year, are not included.

TABLE 8

WORLDWIDE CAPACITY OF DIRECT REDUCTION PLANTS
1973
(In Million Tons of Reduced Product)

Country	Company	Location	Type	Start-up Year
	In Commercial Operation			
Mexico	Hojalata y Lamina, S.A.	Monterrey	HyL	1957/1960
	Hylsa de Mexico, S.A.	Puebla	HyL	1969
	Tubos Aceros de Mexico, S.A.	Vera Cruz	HyL	1967
U.S.A.	Oregon Steel Mills	Portland, Ore.	Midrex	1969
	Georgetown Steel Corp.	Georgetown, S.C.	Midrex	1971
So. Africa	Highveld Corp. Ltd.	Witbank	SL	1968
Greece	Larco Mining & Metall Co.	Larymna	SL	Before 1968
W. Germany	Hamburger Stahlwerke	Hamburg	Midrex	1971
New Zealand	New Zealand Steel Ltd.	Glenbrook	SL	1968
	In Start-up or Final Construction Stage			
Brazil	Usina Siderurgica da Bahia, SA	Aratu	HyL	1973
	Aços Finos Piratini, SA	Charqueadas	SL/RN	1973
Venezuela	Orinoco Min'g Co(US Steel Co)	Ciudad Guayana	HIB	1972
Canada	SIDBEC-DOSCO, Ltd.	Contrecoeur, Que.	Midrex	1973
Mexico	*Hojalata y Lamina, SA	Monterrey	HyL	1973
So. Africa	Dunswart Iron & Steel Ltd.	Benoni	SL/RN	1973
U. S. A.	Armco Steel Corp.	Houston, Texas	Armco	1972
Japan	*Kawasaki Steel Co.	Kawasaki	NA	1973
	Hitachi Metals Co.	Yasuki	NA	1961
Italy	*Monfalcone Works	Monfalcone	HP	1973
	Miscellaneous			
Canada	**Falconbridge Nickel Mines, Ltd.	Falconbridge	SL/RN	1971
Korea	**Inchon Heavy Industry Co.	Inchon	SL/RN	1970
U.S.A.	**McWane Iron Co. *	Mobile Bay, La.	D-L/M	1971
W. Germany***	Thyssen Niederrhein AG	Oberhausen	Purofer	1970

Source: U.S. Dept. of Commerce Publication - "World Iron-Ore Pellet and Direct-Iron Capacity"; Feb. 1973

* Not included in source material

** Plant shut-down due to operating problems

*** NonCommercial - Pilot Plant

on the findings of a feasibility study that is scheduled for completion before the end of 1973.

Like many other novel technical developments, the new direct-reduction facilities have met with some difficulties. At least 2 projects were abandoned because of continued operating problems, and another was shut down after a series of unfortunate accidents. These 3 cases have been listed in Table 8, under the "Miscellaneous" heading. And, even among the installations now in effective operation, many had to overcome time-consuming and costly setbacks during the construction, start-up, and initial operating periods.

There is no need to describe the various direct-reduction processes or their operating principles; that has already been covered adequately in the literature available to the iron-ore and steel industries. What needs to be emphasized is that the new technique is already available as an effective metallurgical procedure for processes that are based on gas for reduction. This is not yet the case for practices that accomplish the reduction by means of solid carbon.

It is a measure of how important the direct-reduction development is to the iron-ore and steel industries that, notwithstanding several setbacks at projects based on solid carbon reductants, ironmakers and steelmakers maintain their strong interest in the coal-based processes. They expect a breakthrough by or before the end of 1975. The reason for such a general continuation of interest and "loyalty" to the idea of direct reduction must lie in the fact that realistic and experienced iron-ore producers, ironmakers, and steel operators recognize that the development is increasingly needed in their industries. For if the world's steel producers are to reach and sustain an output level of one billion tons a year after 1980, then direct-reduction technology will be essential to complement the industry's conventional practice.

The question concerning direct reduction, therefore, does not relate to the adequacy of available techniques, for they are already here for the gaseous reductant processes, but rather to economics. The point at issue isnot whether direct reduction can replace existing ironmaking procedures, which in fact it cannot do, but whether that new technology can be applied effectively to special situations where suitable ores and fuels exist. To such an inquiry, the answer is evidently a positive one, if we are to judge from the experiences in Mexico.

That conventional steelmaking practice involving blast-furnace/oxygen-blown units is complementary rather than competitive to the route using direct-reduction/electric-furnace combinations is implicit in Table 7. Clearly, the introduction of 6% prereduced materials in 1980 and 10% in 1985 does, in fact, mean a reduction in pig-iron requirements of corresponding magnitudes. But this will hardly pose a threat to the use of the blast furnace, which will still be needed to smelt some 550 million tons of pig iron annually from well over 1000 million tons of iron ore and agglomerates. As a matter of fact, some one-third of the estimated prereduced materials consumptions will be used in pig-iron production, as shown in Tables 9 and 10, which need little explanation.

TABLE 9

ESTIMATED METALLIC RAW MATERIALS CONSUMPTIONS FOR WORLDWIDE STEEL PRODUCTION: 1975 to 1985
(In Millions of Metric Tons)

Year	Raw Steel Production	Estimated Consumptions		
		Pig Iron	Scrap	Prereduced Ore
1975	735	460	316	11.2
1980	915	545	395	42.0
1985	1025	555	460	88.0

TABLE 10

ESTIMATED DEMAND FOR PREREDUCED IRON ORE WORLDWIDE: 1975 - 1980 - 1985
(In Millions of Metric Tons)

Year	For Steel Production		For Iron Production		Total
	MT	%	MT	%	MT
1975	11.2	100	--	--	11.2
1980	42.0	65	22.0	35	64.0
1985	88.0	71	36.0	29	124.0

In addition, Table 11 is of interest.

TABLE 11

WORLDWIDE STEELMAKING PRACTICE FORECASTS: 1975 - 1980 - 1985
(In Millions of Metric Tons & Percent)

Year	Production	BOF		EF		OH		MISC.	
		MT	%	MT	%	MT	%	MT	%
1975	735	387	52.7	106	14.4	226	30.7	16	2.2
1980	915	567	62.0	183	20.0	157	17.1	8	0.9
1985	1025	666	65.0	287	28.0	67	6.5	5	0.5

Table 11 illustrates the expectation that oxygen* and electric steelmaking practices together will account for two-thirds ([illegible]) of the world's total raw-steel output in 1975. (For 1970, the figure was approximately 50%). Both practices will increase steadily, reaching a total of [illegible] of the global steel production in 1980, and 95% in 1985. The conventional iron and steelmaking practice will evidently advance more rapidly than the direct reduction-electric furnace operations until after [illegible]. Not until then is there likely to be enough prereduced iron ore to meet the industry's demand for such material. Present trends indicate that by the year 2000 there may be a division between "hot steelmaking" (blast furnace/BOF) and "cold steelmaking" (prereduced iron ore/electric furnace) that will stabilize at a ratio of approximately 57% to 41%, with the remaining 2% being produced in modified open-hearth units without oxygen.(21)

The figures in Table 11 are used in developing a scenario of the worldwide steel producing operations in the year 1980, shown in Table 12. This provides a rationale for the pig-iron and directly reduced iron-ore consumptions listed in Table 9. Similar calculations may be developed for other years and individual locations. The point of interest in this case is that in 1980, steel production by blast furnace/BOF practice will dominate the industry, globally.

Coke and Coking Coal "Savings"

Table 13 presents the results of a calculation of pig-iron requirements, with and without prereduction practice. The correspondence with the figures determined in Table 12 is sufficiently close to support the validity of both computations. The results in Table 13 indicate the possibility of reducing the necessary tonnages of pig iron for steelmaking by nearly 10% in 1975, 15% in 1980, and 20% in 1985, through the introduction of direct-reduction technology in the global ironmaking and steel-production operations.

Such "savings" in pig-iron requirements will obviously lower the coke and coking coal requirements needed in the 1975 to 1985 period by approximately the same proportions. Considering the rising price schedules for coking coals and coke that are expected throughout the industry because of the great changes that are taking place in the energy-supply situations of the world, the positive effect of prereduction applications is evident. Furthermore, the lowered investment requirements for blast-furnace and coke-oven capacities are likely to be considerable compared to the corresponding capital needs for direct-reduction installations.

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(21) "Scrap, Prereduced Iron Ore and Electric Furnace Steelmaking in the 1970 Decade", by J.R. Miller; 42 Annual Convention, Institute of Scrap Iron and Steel, Los Angeles; January, 1970.

* Includes possible oxygen practices that modify current blowing procedures.

TABLE 12

FORECAST METALLIC REQUIREMENTS FOR STEELMAKING
Worldwide, in Millions of Metric Tons
1980

Estimated Raw Steel Production = 915 million tons

By O_2 Methods -- 62% = 567 MM tons
By Electric Furnace -- 20% = 183 MM tons
By Open Hearth -- 17.1% = 157 MM tons
By Bessemer -- .9% = 8 MM tons

Process and (Yield)	Production and (Share)	Metallic Material Inputs Pig Iron (P) MM tons	 Scrap (S) MM tons	 Metallized Ore (O) MM tons
Oxygen (92%)	567 MM tons			
	P = 392 MM tons = (69%)	425		
	S = 153 " " = (27%)		166	
	O = 22 " " = (4%)			24
Electric Furnace (94%)	183 MM tons			
	S = 143 MM tons = (79%)		152	
	O = 38 " " = (21%)			40
Open Hearth (90%)	157 MM tons			
	P = 95 MM tons = (60%)	104		
	S = 50 " " = (32%)		56	
	O = 12 " " = (8%)			13
Bessemer (90%)	8 MM tons			
	P = 7 MM tons = (93%)	8		
	S = 1 " " = (7%)		1	
Sub-Totals - Contained Iron		537 MM tons	375 MM tons	77 MM tons
- Metallized Iron (92%)				83 MM tons
Acceptance Factor - (50%)		+22	+20	-42
Transfer Losses - (1 1/2%)		+ 8	-	+ 1
TOTAL		567 MM tons	395 MM tons	42 MM tons

TABLE 13

WORLDWIDE PIG IRON PRODUCTION FORECASTS - BY REGIONS WITH AND WITHOUT USE OF PREREDUCTION: 1975 TO 1985
(In Millions of Metric Tons)

Region	Approx. P/S (a)	1975 With PR	1975 No PR(b)	1980 With PR	1980 No PR	1985 With PR	1985 No PR
RLD TOTAL	0.69	459.7	504.0	545.5	637.0	555.5	717.0
rth America	0.66	88.0	99.3	100.5	114.7	101.8	121.0
U.S.A.	0.66	81.0	89.1	88.6	101.0	89.3	107.6
in America	0.66	17.1	18.5	24.4	29.0	25.6	32.3
rgentina	0.64	1.8	1.9	2.8	3.1	3.2	5.1
razil	0.68	6.8	7.5	10.4	12.6	10.7	15.0
exico	0.68	3.7	4.1	5.9	6.9	6.3	6.2
enezuela	0.67	1.2	1.3	1.7	2.0	1.9	2.7
rope - West	0.68	110.8	118.3	128.6	151.0	130.4	167.2
E.E.C. & U.K.	0.74	[illegible]	99.4	112.4	129.3	[illegible]	[illegible]
Bel-Luxem.	0.67	14.9	15.7	[illegible]	19.6	[illegible]	[illegible]
France	0.79	17.3	18.2	18.2	[illegible]	18.4	[illegible]
Germany (W)	0.70	31.9	34.3	37.2	41.4	37.6	[illegible]
Italy	0.62	6.9	9.9	9.6	11.6	10.1	[illegible]
Netherlands	0.66	[illegible]	4.1	4.2	4.8	4.3	5.4
U.K.	0.66	14.3	17.2	17.2	21.4	17.7	[illegible]
ustria	0.69	3.1	3.5	3.7	4.1	3.8	4.8
pain	0.63	5.7	6.3	9.0	10.1	9.2	11.5
weden	0.50	3.3	3.5	4.1	4.5	4.2	5.0
rope - East	0.70	118.9	130.9	137.5	162.0	149.4	180.2
U.S.S.R.	0.72	89.2	97.2	97.5	115.2	96.2	[illegible]
zechoslovakia	0.64	9.0	9.6	10.3	12.8	10.6	13.4
ermany (E)	0.69	4.5	4.8	5.8	6.9	5.9	7.0
oland	0.68	9.4	10.2	10.8	12.2	10.4	13.6
umania	0.67	6.2	6.7	7.2	8.0	7.3	8.7
ia	0.69	105.1	116.6	127.2	148.3	129.6	[illegible]
Japan	0.68	82.5	91.8	96.0	112.9	97.2	[illegible]
China	0.82	17.4	18.0	17.8	20.5	18.0	18.7
India	0.82	6.0	6.6	8.8	9.8	8.8	10.7
rica & Mid-East	0.72	6.3	6.5	8.8	9.4	9.7	12.0
ep. of So. Africa	0.72	5.6	5.8	6.8	7.2	6.9	10.1
eania	0.71	13.5	13.9	18.5	22.6	19.6	27.0
ustralia	0.73	13.5	13.9	17.1	21.9	17.4	26.5

(a) P/S = Pig iron to raw steel ratio
(b) PR = Prereduced iron ore

Tables 14, 15, and 16 summarize estimated coke requirements, worldwide, by regions and for a number of selected countries, for 1975, 1980, and 1985, with and without the use of prereduced iron ore. In Table 17, these forecasts are translated into the corresponding tonnages of coking coal that will be needed to sustain global steel-industry operations during those years. The impact of the introduction of direct-reduction technology, even on the limited scale foreseen in Table 12, becomes impressively clear. For example, the data in Table 15 show that it is possible in 1980 to lower the estimated consumption of [illegible] million tons of blast-furnace coke by about 13%, or 39 million tons, if the forecast quantity of 64 million tons of directly reduced metallized iron ores are used in that year. Similar reductions in furnace coke use are also indicated for 1975 and 1985 -- 22.5 million tons, or 9%, in the first case and 67 million tons of coke, equal to nearly 22%, in the second.

Table 17 presents those results in terms of coking coal consumption. For 1980, the estimated coal needed for pig-iron production could be decreased 57 million tons from 420 million tons to 363 million. Aside from the 13% reduction in coking coal costs incidental to pig-iron production, the consequent lowering of coke-oven emissions by approximately the same percentage must, of itself, add strong support to the industry's general interest in direct-reduction technology.

Scrap

The pattern of steel-scrap consumption in the steel industry has in recent years reflected the following distribution: 83% for steelmaking, 3.4% for pig-iron production in blast furnaces, and 13.4% in iron foundries.(22) Given the steelmaking scrap requirements estimated in Table 9, total worldwide scrap demands of about 380 million, 480 million, and 555 million tons must be satisfied in 1975, 1980, and 1985, respectively.

These are unprecedented tonnages of scrap consumption. Even the quantities indicated for steelmaking alone—316 million tons in 1975, 395 million tons in 1980, and 460 million tons for 1985—exceed any past experience of the steel industry. In 1969, a record year for scrap production, global consumption of scrap was about 330 million tons, compared with some 410 million tons of pig iron. The steelmaking process obviously depends on iron ore as the principal mineral reserve. In practice the metallic component is provided in the form of pig iron, but scrap is a surprisingly large second source of iron units.

Scrap and pig iron are, in fact, alternatives for each other within rather wide limits, in steelmaking. Yet, the proportions of scrap and pig iron consumed in the established steel-producing centers remain relatively unchanged notwithstanding a natural tendency to respond strongly to modulations of technical and economic condition. For example, the replacement of open-hearth practice by oxygen blowing, one a much greater consumer of scrap than the other,

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(22) "Problems Relating to Iron and Steel Scrap"; United Nations Document ST/ECE/STEEL/33; Sales No.E.71.IIE/Mim12; Table 1; New York, 1971

TABLE 14

ESTIMATES OF COKE REQUIREMENTS FOR BLAST FURNACE AND TOTAL USES WORLDWIDE - 1975
(in Millions of Metric Tons)

Region	Fuel Rate Kg	Coke Rate Kg	Without Prereduction			With Prereduction		
			Pig Iron MT	BF Coke MT	Total Coke MT	Pig Iron MT	BF Coke MT	Total Coke MT
WORLD	552	505	504	254.6	332.4	460	232.1	303.1
North America	563	525	99.3	52.2	58.8	88.0	46.2	52.0
USA	560	520	89.1	46.3	51.6	81.6	42.5	47.5
Latin America	615	600	18.5	11.1	12.1	17.1	10.3	11.2
Brazil	600	585	7.5	4.4	4.7	6.8	4.0	4.2
Mexico	615	600	4.1	2.5	2.8	3.7	2.2	2.4
Europe - West	580	530	118.3	63.0	91.3	110.6	58.6	85.2
(EEC & UK)	(575)	(520)	(99.4)	(54.0)	(81.7)	(92.5)	(49.2)	(76.5)
Belg-Luxem.	610	570	15.7	8.9	11.0	14.9	8.5	10.5
France	625	565	18.2	10.3	14.1	17.3	9.7	[illegible]
Germany (W)	563	520	34.3	17.8	27.0	31.1	16.2	25.4
Italy	600	555	9.9	5.5	11.3	8.9	5.0	10.8
Netherlands	590	550	4.1	2.5	4.1	3.8	2.1	3.8
UK	580	530	17.2	9.2	13.2	14.3	7.6	11.6
Spain	600	550	6.3	3.5	4.5	5.7	3.1	4.4
Europe - East	535	505	130.9	66.2	93.0	118.9	60.0	84.0
USSR	525	485	97.2	47.1	56.6	89.2	43.2	52.0
Czechoslovakia	610	590	9.6	5.7	8.6	9.0	5.3	7.9
Germany (E)	625	610	4.8	2.9	5.7	4.5	2.7	5.3
Poland	615	600	10.2	6.1	11.6	9.4	5.6	10.7
Rumania	625	580	6.7	3.9	7.6	6.2	3.6	7.0
Asia	525	440	116.6	51.3	64.5	105.1	46.3	58.4
Japan	476	385	91.8	35.2	43.0	82.5	31.8	38.6
China	700	680	18.0	12.2	14.0	17.4	11.8	13.6
India	640	610	6.6	4.0	5.7	6.0	3.7	5.3
Africa & Mideast	615	585	6.5	3.8	4.5	6.3	3.7	4.4
Rep. So. Africa	615	585	5.8	3.4	4.1	5.6	3.3	4.0
Oceania	530	500	13.9	7.0	8.2	13.5	6.8	7.9
Australia	530	500	13.9	7.0	8.2	13.5	6.8	7.9

TABLE 15

ESTIMATES OF COKE REQUIREMENTS FOR BLAST FURNACE AND TOTAL USES
WORLD [illegible] - [illegible]
(In Millions of Metric Tons)

Region	Fuel Rate kg	Coke Rate kg	Without Prereduction			With Prereduction		
			Pig Iron MT	BF Coke MT	Total Coke MT	Pig Iron MT	BF Coke MT	Total Coke MT
WORLD	492	445	637	291.[illegible]	364.1	545	252.1	315.[illegible]
North America	525	460	1[illegible]4.7	5[illegible].0	59.5	100.5	48.2	53.0
USA	515	460	101.6	46.8	55.6	86.0	42.5	[illegible]
Latin America	550	520	29.0	16.3	17.8	24.4	13.7	14.9
Brazil	570	545	12.6	6.9	7.6	10.4	5.7	6.3
Mexico	580	555	6.9	3.8	4.2	5.9	3.3	3.6
Europe - West	545	500	1[illegible]1.0	79.5	10[illegible].8	126.6	64.3	69.4
(EEC & UK)	([illegible])	([illegible])	([illegible])	([illegible])	([illegible])	(102.7)	(50.8)	(55.7)
Belg.-Luxem	550	510	19.6	9.4	11.3	16.0	8.2	9.4
France	555	520	21.1	10.7	13.[illegible]	16.2	9.3	11.6
Germany (W)	510	475	[illegible].1	19.5	2[illegible].0	37.2	17.4	25.4
Italy	560	515	11.6	6.0	10.8	9.6	5.0	9.0
Netherlands	555	515	4.8	2.5	3.2	4.2	2.2	2.6
UK	540	490	21.4	10.5	12.6	17.2	8.4	10.5
Spain	560	520	10.1	5.2	6.5	9.0	4.6	5.8
Europe - East	500	470	162.0	76.2	102.0	137.5	64.6	86.5
USSR	490	450	115.2	59.0	58.0	97.5	44.0	49.0
Czechoslovakia	555	530	12.2	6.5	9.5	10.3	5.5	7.2
Germany (E)	560	540	6.9	3.7	6.1	5.8	3.1	5.1
Poland	555	530	12.[illegible]	6.5	10.7	10.2	5.4	8.9
Rumania	560	515	8.0	4.1	6.8	7.2	3.7	6.1
Asia	455	3[illegible]5	1[illegible]8.3	54.6	62.6	127.2	47.8	55.0
Japan	425	335	112.9	37.8	43.8	96.0	32.2	37.4
China	600	570	20.5	11.7	13.5	17.8	10.2	11.7
India	620	570	9.8	5.8	8.0	8.8	5.2	7.2
Africa & Mideast	575	535	9.4	5.0	5.9	8.8	4.7	5.5
Rep.So.Africa	575	535	7.2	3.6	4.6	6.8	3.6	4.3
Oceania	500	475	22.6	10.7	12.5	18.5	8.7	10.2
Australia	500	475	21.9	10.3	12.0	17.1	8.2	9.5

TABLE 16

ESTIMATES OF COKE REQUIREMENTS FOR BLAST FURNACE AND TOTAL USES
WORLDWIDE - 1985
(in Millions of Metric Tons)

Region	Fuel Rate kg	Coke Rate kg	Without Prereduction Pig Iron MT	Without Prereduction BF Coke MT	Without Prereduction Total Coke MT	With Prereduction Pig Iron MT	With Prereduction BF Coke MT	With Prereduction Total Coke MT
WORLD	480	437	710	309.2	371.0	595	281.9	[illegible]
North America	490	450	121.0	54.4	60.9	101.8	45.7	51.5
USA	480	440	107.6	47.5	52.3	89.3	39.2	43.6
Latin America	545	510	32.3	16.5	18.2	25.6	13.1	14.4
Brazil	520	485	15.0	7.3	8.0	10.7	4.9	5.4
Mexico	530	490	8.2	4.0	4.4	6.3	3.1	3.4
Europe - West	510	470	167.2	78.5	100.2	130.4	61.5	80.0
(EEC & UK)	(505)	(495)	(142.8)	(67.0)	([illegible])	(104.5)	(50.6)	([illegible])
Belg.-Luxem.	520	480	20.2	9.7	11.3	16.4	7.9	9.1
France	520	480	24.1	11.6	14.5	18.4	9.9	12.3
Germany (W)	490	450	44.6	20.1	25.9	37.6	17.9	[illegible]
Italy	530	485	13.6	6.6	10.6	10.1	4.9	7.8
Netherlands	520	480	5.4	2.5	3.3	4.3	2.1	2.6
UK	505	455	24.9	11.4	[illegible]	17.7	8.1	9.4
Spain	520	470	11.3	5.3	6.4	9.2	4.3	5.2
Europe - East	465	415	180.2	82.0	102.0	139.4	62.7	78.5
USSR	450	410	128.2	52.5	75.8	98.2	40.3	54.6
Czechoslovakia	510	480	13.4	6.5	8.1	10.6	5.1	6.4
Germany (E)	515	480	7.6	3.7	5.2	5.9	2.9	3.9
Poland	505	485	13.6	6.5	8.6	10.4	5.0	7.0
Rumania	515	465	8.7	4.1	5.8	7.3	3.9	5.5
Asia	435	350	169.3	59.5	74.5	129.0	45.3	57.3
Japan	410	310	121.0	37.6	43.3	97.2	30.4	35.0
China	550	515	26.7	14.8	17.0	18.0	9.3	10.7
India	565	530	10.7	5.7	7.7	8.8	4.7	6.4
Africa & Mideast	525	490	13.0	6.4	7.4	9.7	4.9	5.7
Rep.So.Africa	525	490	10.1	4.9	5.7	6.9	3.4	4.0
Oceania	480	410	27.0	11.9	13.8	19.6	8.7	9.9
Australia	480	410	25.3	11.3	13.4	17.4	7.7	7.9

TABLE 17

ESTIMATES OF COKING COAL REQUIREMENTS
(In Million Metric Tons)

Region	Coal/Coke Yield	1975				1980				1985			
		No PR **		With PR **		No PR **		With PR **		No PR **		With PR **	
		for BF	Total	for BF	Total	for BF	Total	for BF	Total	for BF	Total	for BF	Total
WORLD	-	[illegible]	478.1	324.5	[illegible]	419.5	[illegible]	363.2	[illegible]	445.5	545.3	[illegible]	[illegible]
North America	.690	75.7	85.1	67.0	75.4	[illegible]	[illegible]	70.1	[illegible]	76.0	88.2	[illegible]	74.7
Latin America	.680	15.3	17.0	15.2	16.3	[illegible]	21.2	20.2	21.9	24.3	[illegible]	19.3	21.2
Europe - West	.705	[illegible]	139.5	83.5	121.0	[illegible]	[illegible]	91.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Europe - East	.700	[illegible]	132.8	85.8	119.8	[illegible]	117.1	92.4	123.6	127.1	[illegible]	89.5	112.0
Asia	.655	75.0	94.5	67.6	85.4	[illegible]	91.5	69.9	80.5	67.5	100.9	[illegible]	94.4
Africa & Mideast	.680	5.6	6.8	5.4	6.5	[illegible]	8.7	[illegible]	[illegible]	9.4	10.9	7.2	8.4
Oceania	.685	10.5	12.0	9.8	11.5	15.0	18.3	12.7	14.9	17.4	20.2	12.7	14.4
In which are included:													
U S A	.690	67.3	75.0	61.7	68.9	70.8	78.1	61.7	67.8	69.3	76.0	56.8	62.4
Brazil	.680	6.5	[illegible]	5.9	[illegible]	10.2	11.2	8.4	9.3	10.7	11.8	7.2	8.0
EEC & UK	.700	77.1	116.8	70.3	105.0	84.2	112.2	72.6	98.1	[illegible]	110.0	[illegible]	[illegible]
U S S R	.690	58.4	82.0	62.6	75.4	[illegible]	84.1	63.8	71.1	[illegible]	84.0	[illegible]	[illegible]
Japan	.670	52.5	64.2	47.5	56.0	54.5	65.5	48.1	55.4	57.1	64.7	[illegible]	52.3
China	.638	17.6	20.3	17.2	19.7	17.0	19.6	14.8	17.0	21.5	24.7	13.5	15.8
Australia	.685	10.3	12.0	9.9	[illegible]	15.0	17.5	12.0	13.9	16.9	[illegible]	11.3	11.5

** PR = Prereduction

has not been accompanied by any [illegible] overall change in scrap usage in the steel industry since 1955. [illegible] and scrap consumed to [illegible] production [illegible] in 1955 for the Common Market Countries and [illegible] in 1968; in the U.S., the figures for those years were .464 and .48[illegible].

The relative stability of the proportion of scrap consumed in overall steel operation, regardless of what steelmaking practices may be in prevailing use, is largely due to the fact that much of the scrap is generated in the steel production and transformation operations themselves. The first gives rise to "plant scrap", the second to "process scrap". Plant scrap (also "circulating scrap") constitutes roughly half the total scrap input for steel production. The balance, from about 45% to 60%, is "purchased scrap", which includes "process scrap" and deliveries from collectors, processors, and suppliers outside the steel industry itself. During the past decade purchased scrap has tended to decrease: from 48% in 1955 to 45% in 1968 in the EEC countries; 44% to 39% in the U.S.; 43% to [illegible]% in Poland; and from 58% to 55% in Japan, for the same years.

The geographical distribution patterns of scrap consumption parallel crude-steel production; but only approximately. In 1969, scrap usage in the United States, Western Europe, Eastern Europe, and Japan equalled [illegible]%, [illegible]%, [illegible]%, and 11%, respectively. These shares of the global scrap consumption compare with 22.8%, 27.1%, 25.6%, and 14.5% that were the respective proportions of steel output in these regions for that year.

The centers of scrap demand have therefore been reflected in locational shifts similar to those that have marked steel production over the past two decades. An international system of trade in scrap has emerged in which some 8 million to 9 million tons of metal moved in 1955; by 1969 the volume of scrap traded in the world market was approximately 18 million tons. This doubling of scrap exports and imports reflects a somewhat greater rise in growth rate than for total scrap consumption, which increased 83% in rising to 330 million tons in 1969 from 180 million tons in 1955.

Two-thirds of the scrap traded in the world market is provided by only three countries: the United States (a net of 8 million tons, or 45% in 1969), France (10%), and the USSR (8%). Three countries also receive nearly two-thirds the scrap traded; Italy (5.1 million tons, or 29%), Japan (27%), and Spain (7%). It is interesting to note that, on the import side, Japan has reduced its receipts from 38% in 1960, while Italy has remained rather steady but with intervening fluctuations; Spain has emerged as an increasingly significant consumer of foreign scrap since 1965. On the export side, the USSR has moved up relatively strongly during the 1960's, France has maintained an even level in terms of percentages, and the U.S. has declined from 60% in 1960 to 40% in 1968; the fall-off was reversed in 1969 and 1970.

World trade in scrap is thus seen to move with fluctuations of large magnitude within generally fixed long-term patterns. For example, scrap consumption in the U.S. fell from 95 million tons in 1969 to 85 million tons in 1970 as plant-scrap generation declined from 56 million tons to 52 million; at the same time scrap exports from the U.S. moved up from 9 million to 10 million tons. Such variations in the supply of scrap are reflected in wide price swings, that have become established features of the steel-scrap industry. The amplitude of the swings have increased and come more rapidly since 1963.

Concern about environmental pollution has added pressures for more recycling of solid wastes, so that larger amounts of process scrap may be available in more usable forms and condition. It has also brought out renewed interest in a long-neglected potential source of steel scrap units: "capital scrap", which consists of obsolete iron and steel materials that have been discarded, but may be recovered, processed, and salvaged. Capital scrap accumulations ("obsolete scrap" and "salvage scrap") have been built up in most countries of the world where steel has been consumed for a large number of years. Such sources have been tapped only where scrap collection and supply organizations have been set up. In other countries, the obsolete scrap exists —often in substantial amounts—but no means for effective recovery is available. It is estimated that the tonnage of this kind of scrap might readily be increased by 50% or more.

The quantity of obsolete scrap used depends greatly on quality considerations. Chemical residuals, such as copper, tin, and arsenic, introduce brittleness tendencies; chromium, lead, and zinc complicate steelmaking practices; nickel, molybdenum, and cobalt lower welding capabilities. These characteristics illustrate some of the problems introduced by residual metals.

Physical features, mainly size, dimensions, density, cleanliness, and transportability, also influence the usefulness of steel-scrap materials. As steel consumers have become more aware of and more insistent in their demands for quality steel product, specifications for scrap have become narrower and more thoroughly checked. A prime advantage cited for prereduced iron ore is that, like pig iron, it is mostly a processed virgin metallic material and therefore generally of uniform size and shape, and also free of residuals.

Given scrap in proportionately larger amounts in the future than in the past, the question remains whether or not the tonnages stated in Table 9 will be available. For the forecast steel production tonnages, the steel scrap required totals 375 million tons in 1975, 455 million tons in 1980, and 555 million tons in 1985. Of those quantities, 316 million tons, 395 million tons, and 460 million tons are to be consumed in raw-steel production. An analysis of past rates of plant and process scrap generation and determination of capital scrap potentials have yielded a reply that the global scrap requirements for the next 15 years may be available, with about 1% excess in 1975, but with little or no latitude for error or change in the assumed conditions for 1980 and 1985. This is shown in Table 18.

The figures in Table 18 are obtained by applying several relatively constant factors, some of which have already been described. For example, the 1975 estimates are based on the 56%-44% division between process and capital scrap portions of the total consumption recorded for 1969. The 185 million tons of plant and process tonnage is increased in proportion to the anticipated rise for 1975 compared with 1969, and then by another 10% to account for the increased rate of availability of process scrap with rising steel demand.(23) A similar higher availability rate is applied for capital scrap generation, with a variable factor (5% for 1975, 15% for 1980, and 33% for 1985) because salvage scrap accumulations increase with time.

TABLE 18

ESTIMATED STEEL SCRAP GENERATION POTENTIAL WORLDWIDE: 1975-1980-1985
(In Millions of Metric Tons)

Year	Raw Steel Production	Estimated Scrap Required	Potential Scrap Generation					
			Plant & Process		Capital		Total	
1969	577	330	185	56%	145	44%	330	100%
1975	735	375	254	65%	152	35%	406	100%
1980	910	480	317	65%	167	35%	484	100%
1985	1025	555	360	65%	193	35%	553	100%

The anticipation for plant and process scrap in 1975 is therefore:

$$S_p = (185)(735/577) + (185)(0.10) = 254 \text{ million tons,}$$

and for capital scrap:

$$S_c = (145)(1.05) = 152 \text{ million tons;}$$

together, the two components make up the estimated scrap potential for 1975 (S_{75}) of 406 million tons. Similarly,

$$S_{80} = (185)(910/577) + (254)(0.10) + (145)(1.15) = 484 \text{ million tons;}$$

and, $$S_{85} = (185)(1025/577) + (317)(0.10) + (145)(1.33) = 553 \text{ million tons.}$$

It is pertinent to note that since 1969 there has been great emphasis in the scrap industry on the development and use of effective fragmentizing and other processing equipment, in a concerted effort to minimize solid waste pollution and to make greater use of the potential capital scrap pool. This will be particularly important in the late 1970's and in the 1980 decade, as scrap availability becomes increasingly limited.

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(23) "Problems Relating to Iron and Steel Scrap"; UN Document ST/ECE/STEEL/33; Sales No. E.71.II.E.Mim.12; New York, 1971; p 86

A similar conclusion has been reached by Elliott of MIT (24) for the situation in the United States. He observes: "If there were no exports of scrap from the U.S., scrap would be in a precarious balance in 1975, and the shortfall in 1980 would equal 7 million tons, based on a forecast of steel production in 1980 of 175 million net tons". In this paper, U.S. raw-steel production in 1980 is estimated at 155 million metric tons or 170 million net tons. Scrap requirements and availability are almost in balance after 1975, and, although "the scrap situation is tight," there is no shortfall. The reason is possibly to be found in the assumed use of approximately 10 to 12 million tons of directly reduced iron ore in the United States in 1980. This possibility does not escape Prof. Elliott. He points out that "If the U.S. integrated steel producers increased hot metal production by 5 million net tons in 1975 and 15 million net tons by 1980, the projected shortfall in scrap would be avoided. This would result in a considerable lowering in the production of electric furnace steel unless metallized ore were used to offset the scrap deficiencies anticipated."

ON-SITE IRON-ORE PROCESSING

Up to this point, the following forecasts or observations have been made:

1. Iron ore has become one of the world's most important commodities of international trade. Demand for steel products is growing rapidly and universally, and corresponding expansions in steel output and use are expected. These will stimulate continued growth of the world market for iron ore at a high level.

2. Raw steel production and consumption are expected to increase worldwide from approximately 600 million tons in 1970 to 915 million tons in 1980 and 1025 millions in 1985. Taken together, the developing countries of Latin America, Asia, and Africa are likely to expand their 1970 share of 8% to approximately 12% by 1985.

3. Substantial expansions in iron-ore production are forecast: from 750 million tons of crude ore in 1970 to 1080 million tons and 1250 millions in 1980 and 1985. The developing countries are expected to provide up to about 30% of the future outputs. The 1970 iron-ore trade of around 250 million tons is foreseen as advancing to about 550 million tons by 1980.

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(24) "Reclaimed Scrap and Solid Metallics for Steelmaking", by J.F. Elliott; AIME Annual Meeting, Feb. 1972, San Francisco

4. Iron-ore demand and consumption will be increasingly for higher-grade [illegible]. On a world scale, run-of-mine ore will rise from [illegible] million tons in 1970 to [illegible] million tons in 1985, but this will be a percentage decline from [illegible] to [illegible]. Sinter fines will similarly register a growth in tonnage, from 350 million tons (1970) to [illegible] million tons (1985), with a fall-off in percentage from [illegible] to [illegible]. On the other hand, the worldwide increase in oxide pellet consumption from 100 million tons in 1970 to [illegible] millions in 1985 will represent an advance from 14.1% to 18.5%. The balance is expected to be taken up by a new form of pretreated ore — directly reduced materials for which the estimated demands are 11 million tons by 1975, 64 million tons in 1980, and 124 million tons in 1985.

5. Directly reduced materials are already widely recognized as well-suited for use in both ironmaking and steelmaking because they offer (a) preprocessed and metallized iron units that may be used to sweeten blast-furnace burdens with resulting reductions in coke rate and increases in specific iron outputs; (b) possibilities for continuous charging to electric furnace, permitting more effective use of furnace time, (c) an excellent low-residual raw material to supplement anticipated limitations in steel scrap supply, after 1980; (d) lowered fume and dust emissions that will ease associated environmental pollution tendencies; and (e) greater possibilities for relatively small steel-plant operations keyed to the special local needs of many less-developed areas.

The above findings suggest broad opportunities for greater participation in iron-ore industry (and, to a lesser degree, steel industry) activities, in some developing countries, especially those with important iron ore reserves.

Current On-Site Operations

In today's highly-interrelated world system, closer knit than ever by rapid and easy means of transport and communication, there are more and more possibilities in the developing countries for on-site and in-country operations associated with the production of iron ore, iron, and steel. A sizable experience record of such activity has already been established, as large tonnages of iron-bearing minerals are being processed and pretreated in nearly every iron-ore producing country. In some of these places, steelworks have been erected, usually but not always of small or modest size. A century ago, steel plants were built in Spain and Sweden; and some 50 years ago works were erected in Australia, South Africa, India, Canada, Mexico, and Brazil. Following World War II, steel operations were introduced elsewhere in Latin America, Africa, and more recently, into Western Australia, Finland, the Middle East, and Southeast Asia.

Nevertheless, the participation of the developing countries in working the iron ores extracted from deposits within their borders has been altogether disproportionate. In absolute terms, the figures of iron and steel produced are not negligible, but they [illegible] in comparison. The combined output of raw steel from Latin America, Africa, and Asia (with Japan and the Republic of South Africa excepted), totaled 27 million tons in 1970 and may equal [illegible] million and 100 million tons in 1975 and 1985. One hundred million tons is a sizable quantity of steel, but all the developing countries, taken together, now produce less than 4% of the world total of steel; given a great surge of activity during the next decade, that figure may be increased to 12%. This disparity is given emphasis by the fact that 40% of the world's resources of iron ore comes from developing countries.*

This condition is not unique to iron ores and the iron and steel industries based on them. Similar distortions can be cited in the mining and processing operations of bauxite, alumina, and aluminium; copper ores and copper; nickel sulfide and oxide ores and nickel; and many others. But, because of the large magnitudes involved and the great importance of iron and steel in the industrial life of every country, the iron-ore operation has been an initial point of concern. In 1966, the Secretariat of the U.N. Conference for Trade and Development sponsored a study of the "Prospects for Exports of Processed Iron and Ore from Developing Countries" (25) that concluded: (a) the developing country share of global iron-ore production "will not change appreciably in percentage terms, (remaining) 27.7% in 1975 . . ."; (b) "the installation of new or additional processing facilities at iron ore mines will generally be found economically sound . . . For the upgrading and segregation of fines for sintering and for the production of pellets, the differential between added production costs and increased sales is favorable . . ."; (c) "a generally favorable technical and economic position notwithstanding, the prospects for increased exports of processed iron ore from the developing countries could be compromised by pragmatic obstacles . . . that may originate in the developing areas (as well as) in the developed countries"; (d) " . . . industry cooperation between developed and developing countries is already in force (in the iron-ore industry) in many instances . . closely related motivations provide the basis for joint activities that combine the experience and needs of the developed areas with the resources and enthusiasm of the developing countries"; and finally, (e) ". . . opportunities for every kind of pretreatment are widespread in the developing areas".(26)

For the most part, these findings have been confirmed by the iron-ore and the steel industries' experience of the past 5 years, and they may now be broadened to include equal possibilities for in-country production of

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* The calculation applies for total resources of 193 million tons of iron ore in developing areas compared with a world total of 475 million tons (with CPE's excluded). With those countries included, the percent of iron ore resources originating in developing countries equals about 25% of the total.

(25) UNCTAD paper TD/B/C.2/29, 17 April 1967, Trade and Development Board Meeting, Committee on Manufactures, Second Session; Geneva, July 1967

(26) Opus cit.- Chapter VII, pp 69-72

prereduced ores for domestic use and for export. The anticipated expansion in both iron-ore and steel operations provide a strong argument for inc[illegible] tion of iron ore mining and treatment in the source country, and with provision for later extension up to steelmaking as well.

The consideration of the integration of iron-ore and steelmaking activities in developing countries is carried to the liquid raw steel only. Beyond that point, the emphasis of the analysis would have to be shifted from the processing of a mineral commodity to the transformation of the final product, which is a large enough subject to merit a separate study.

Additional Iron-Ore Mining and Treatment in Developing Countries

Given the large quantities of high-grade iron-ore reserves indicated in Table 2, an increase in mine production in the developing countries from a total of 210 million tons in 1970 to 380 millions in 1985* poses little difficulty. These figures do not include outputs from Australian mines, which are mostly operated jointly with companies of several industrially-advanced countries. Although, as noted, the developing nations of Latin America, Africa, and Asia, together, possess some 60% of the world's base iron-ore reserves ([illegible] excluded), their [illegible] are presently likely to remain at a little under 30%. The expected 1985 ratio of .304 (380/1250), does not differ greatly from the .27 ([illegible]) of 1970.

The expansion in relative as well as absolute share of on-site iron-ore mining operations in developing countries need not be argued for in terms of "equity" or "validity", but rather as a viable commercial effort in which investment cost may be profitably offset by economic advantage. This has already been demonstrated in new and expanded iron-mining operations during the past decade, in Brazil, Liberia, Venezuela, Australia, Peru, India, and elsewhere.

Even greater benefits may be foreseen in the coming period as additional quantities of ore and agglomerates are placed into the international market. As already observed, worldwide exports and imports of iron ore are expected to increase to over 400 million tons in 1975 and as much as 550 million tons five years later. These tonnages represent increases of 60% and 120% above the global export level of 250 million tons of iron ores in 1970. In his 1973 annual report, the Director of the U.S. Bureau of Mines has emphasized that, increasingly, the industrial nations will have to depend on mineral reserves deliveries from the developing countries. The rather small rise to the 30% participation in global iron-ore production by those countries, noted earlier, is therefore likely to require upward revision, with reductions in ore-production costs due to economies of scale.

Similarly, more beneficiation work on iron ores at or near the mine site can be expected. There is almost universal agreement among iron-mine operators and iron-ore consumers that the amount of concentration and

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* See Table 4

pretreatment carried out on the mine products will be increased before they are shipped from the site. Larger quantities of iron-ore production automatically mean greater tonnages of ore screening, separation, and sizing. But the main increase in such preparatory treatment will come from steadily more-demanding ore specification regarding chemistry, form, and size. This will automatically promote increased on-site processing with emphasis on oxide pellets and directly-reduced materials production.

Prereduction Operations in Developing Countries

The status of the prereduction development has already been described. Table 8 lists approximately 5 million tons of direct-reduction capacity in commercial operation and another 2.5 million tons that are scheduled to be in production by the end of 1973. A little less than half the installations tabulated are located in developing countries (Mexico, Brazil, and Venezuela). As noted, the Table does not include 2 major projects that represent approximately 6 million tons annually, in the USSR and in Venezuela. If the contracts for these facilities are carried out as reported, the forecast that 11 million tons of directly-reduced capacity will be available in 1975 may be fully confirmed.

Such confirmation will reflect the strong pressures that are supporting the prereduction development. One cannot overlook that the introduction of direct-reduction techniques has recently been held back somewhat as the coal-reductant processes have been confronted by more than a normal share of difficulties. More than three-quarters of the capacity detailed in Table 8 are based on the use of gaseous reductants. Because natural gas is, and in the future, will be, less favorably priced than coal, there is great interest in the solid-coal based processes. More directly, attention is now focused on the results of plant and practice modifications introduced by the New Zealand Steel Co., and in the start-ups of the Krupp installation at Dunswart (South Africa) and the SL/RN Piratini kiln in Brazil. The latter two cases are of special interest because they are concerned primarily with iron values, rather than with an iron-bearing byproduct output incidental to the recovery of some other metal. Notwithstanding past delays and difficulties, an effective kiln process operated with solid coal reductant is expected to be achieved reasonably soon. Until then, the gaseous methods will be available for use.

Because of the delayed entry of the coal-reductant process, it is too early to define the precise role of direct reduction in developing nations. But the source country where the prereduced iron originates is certain to be involved in some way in the development. If the metallized ore is made near the mine, there will be a new on-site operation, probably as an extension to new or existing pellet facilities. If the sponge iron is manufactured at the consuming plant site, additional processing will be introduced to produce low-gangue superconcentrates for this specific purpose. Either activity is likely to be a source of an interesting increase in added-value from the new operations.

Capital Cost

Cost estimates for direct-reduction installations have become extremely difficult to define because of recent changes in currency values, and because there is little consistency in what is included in any bid or estimate by the different prereduction plant suppliers. Evaluations are therefore, at best, educated guesses based on one or more plants that have already been erected. In most of these cases, the available figures are usually second-hand.

The capital cost of the HyL facility is taken as approximately typical for the gaseous reduction process with static or moving beds in a shaft furnace, because more HyL cost figures have been made public. Increased by 15% for overall construction cost rises during the past 18 months, these would come to $37.00 to $43.00 per annual ton of reduced iron capacity for a 250,000 ton per year unit; $33.95 to $40.25 per annual ton for a 500,000 ton capacity plant, and $32.20 to $37.00 per ton for a facility twice as large. But these estimates can only be taken as order-of-magnitude quotations because they do not provide many items needed to have a plant ready for practical operation. The detail estimates for a HyL plant now being built and the actual figures of another erected several years ago give somewhat more reliable results. They indicate that the full specific cost of a 350,000 ton, gaseous reduction plant may be between $47 and $57 per annual ton, and approximately from $42 to $51 per ton for a 1-million ton a year installation, based on estimating cost levels of May, 1973. These figures reflect the experience at Puebla, which was brought to capacity operation in the remarkably short period of 5 to 6 months, with few, if any, serious start-up problems.

In general, the kiln-type installations of solid-reductant process operations should cost (total capital outlay) approximately 10% to 15% less than the gaseous prereduction plants discussed above. The reason lies in the fact that the kiln plant without reforming equipment is somewhat smaller than the gas-reductant facility. Until now (May 1973), no kiln installation has gone into operation "easily", and large alteration and start-up modification expenses have obscured the actual investment requirements. In the meantime, we estimate the specific capital cost of solid-carbon reduction plants at $42 to $51 per ton for a 350,000 ton per year facility and $38 to $46 for a 1 million ton plant.

Production Costs

A large number of estimates have been suggested as the cost of manufacturing prereduced iron ore. These have ranged from $26 per ton of contained Fe to $32 per ton for "large" operations producing 1 million to 1.5 million tons of metallised (85% to 92%) iron from their own ore supply sources, up to a range between $38 and $49.50 per ton of iron in metallised sponge (90%) for "standard" 200,000 ton per year plant processing purchased oxide pellets.(27) Approximately $2.00 should be added when superconcentrated

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(27) Some examples are: Large Plants: $25.85 (by M.M.Fine, Bur. of Mines; 1970), $27.30 (by Battelle Institute-Project for Tasmania, 1968); $29.70 (by J.R.Miller Paper for India, 1971). Standard Plants: $35.20 ("rock-bottom"by M.W.Lowis, Battelle-AIME paper; 1971);$37.60 (by J.R.Miller-Project for USIBA, 1968); $38.05 (Lurgi, New Delhi-Project Proposal, Jan.1971); $48.50 (G.G.Reed-Lurgi, Canada; AIME paper). These numbers, too, should be increased to include 8% to 14% devaluation.

low-gangue materials are used. In view of the devaluation of the dollar since these estimates were made, they should all be raised by 8% to 14%.

For the "large" operation, the material to be processed will represent 50% to 65% of the total production cost; fuel will equal 15% to 18%; conversion labor, materials, and service charges 10% to 17%; and the balance 15% to 20% will be fixed charges. Thus for the $32.10 per ton estimate in a one-million ton plant metallizing high-grade pellets, the following summary applies:

Raw Materials

Pellets (65%) @ 18.5¢/unit		= $18.50	- 58%
Fuel - 15,000 btu @ 35.0¢/MM		= 5.25	- 16%
Conversion			
Labor and Supervision	1.25		
Materials	1.70		
Services	.60	= 3.55	- 11%
Fixed Charges (25% equity)			
$43MM x .75 x 15%		= 4.80	- 15%
TOTAL		= $32.10	- 100%

For the standard 200,000 ton facility, the production cost estimates have been cited around $38.00. At least half the $6.00 difference (between $38.00 and $32.00) goes to fixed charges, and most of the remainder is included in higher conversion costs. Thus:

Iron Ore	= $18.50	- 49%
Fuel - 16,500 btu @ 35¢/MM	= 5.77	- 15%
Conversion	= 6.30	- 16%
Fixed Charges		
$11MM x .75 x 18%/200,000	= 7.50	- 20%
TOTAL	$38.05	- 100%

Brought approximately up-to-date by an addition of about 15%, the estimate is more realistically set at $44 for current conditions.

Metallurgical Values - Raw Steel Base

The comparison of a direct-reduction/electric furnace steelmaking combination with conventional blast-furnace/basic oxygen converter practice shown in Table 19, has been prepared to judge the potential viability of prereduction technology. Three transformation routes are presented, from crude ore to raw steel in the ladle: (a) blast furnace/BOF, (b) solid reductant DR/electric furnace, and (c) gaseous DR/electric furnace. In effect, the comparison is made in terms of the metallurgical value of each combination at the raw-steel level. This base is used as it is the first point in the ironmaking/steelmaking conversion where the product is essentially the same.

The three combinations are subject to the assumption that all are equally operable regarding ore and fuel inputs, site location, market, labor and supervision, financial support, and management. Raw-material prices are assumed as shown; the figures are not necessarily applicable to any particular project or plant but they are quite suitable for comparison.(26)

Table 19 has been recalculated for several plant sizes up to 2 million tons a year, and the results are plotted in Figure II. The immediate observation is that for outputs under 250,000 to 300,000 tons a year the direct reduction/electric furnace combination, particularly the solid reductant processes, may produce steel at a slightly lower cost than blast furnace/BOF practice. This confirms the adaptability of direct-reduction installations for local mini-plant operations.

The solid carbon prereduction process appears capable of producing steel at a lower cost (up to 10%) than the gaseous methods, when both practices use lump ore. This may be expected in view of the generally higher cost of gas compared with coal. When both processes use pellets the difference is rather small. For outputs over 1 million tons a year, gaseous practice seems to have a slight advantage. The improvement that the gaseous processes gain through the use of pellets has been confirmed in the experience at TAMSA and Puebla.

Mutual Interest of Developed and Developing Countries

There thus is wide latitude for increased on-site operations, from agglomeration to prereduction technology, in developing countries with good iron-ore resources. Such added activities could be directed at extending the range of iron ore treatment for export of higher forms of iron-ore product. A portion of this material would also be available for local iron and steel production. Generally, the latter operation would be on a relatively modest scale to meet domestic demands; however, in certain countries (Brazil, Algeria, Australia, Canada), and in some regions (West Africa, the Andean group of Latin America), larger steel-producing enterprises could be established based partly on the export of semi-finished products. But, the validity of such a scenario

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(26) This analysis has been suggested by "Economic and Geographical Considerations Affecting the Choice of Steel Making Routes", by H.R. Mills and G. A. Johnson, presented at Iron and Steel Institute meeting, London, May 1971.

TABLE 12

COMPARISON OF RAW STEEL PRODUCTION COSTS
BLAST FURNACE/BOF, SOLID DR/EF and GASEOUS DR/EF
(Hypothetical Operation - 500,[illegible])

	BF/BOF	SOLID DR/EF	GASEOUS DR/EF
Raw Material			
Iron Ore	15.60	18.50	18.50
Coal	15.50	9.70	-
Limestone	1.05	.50	.25
Scrap	2.05	2.05	2.05
Additions	1.65	1.65	1.65
Ironmaking Conversion			
Electricity	.12	.43	.32
Gas	-	-	8.25
Oil	-	.12	-
Labor	.77	.60	.90
Other	1.68	1.40	2.45
Steelmaking Conversion			
Energy	1.28	6.65	6.65
Labor	1.60	1.92	1.92
Other	1.68	4.03	4.03
General Works Services	2.90	4.60	7.35
Fixed Charges			
Iron Making	9.10	5.00	9.58
Steel Making	5.37	6.40	6.40
TOTAL RAW STEEL COST	$60.55	$63.75	$70.40

Note: the following raw material costs have been assumed:

Iron Ore - R.O.M. (60% Fe) - Lump	$12.50 per ton
Iron Ore - Fines	9.00 " "
Scrap	34.00 " "
Coal - coking	24.00 " "
Coal - non-coking	15.50 " "
Electricity	1¢ per kwh
Natural Gas	48¢/1000 cf
Scrap in steelmaking charge	27%
Fixed Charges	17%

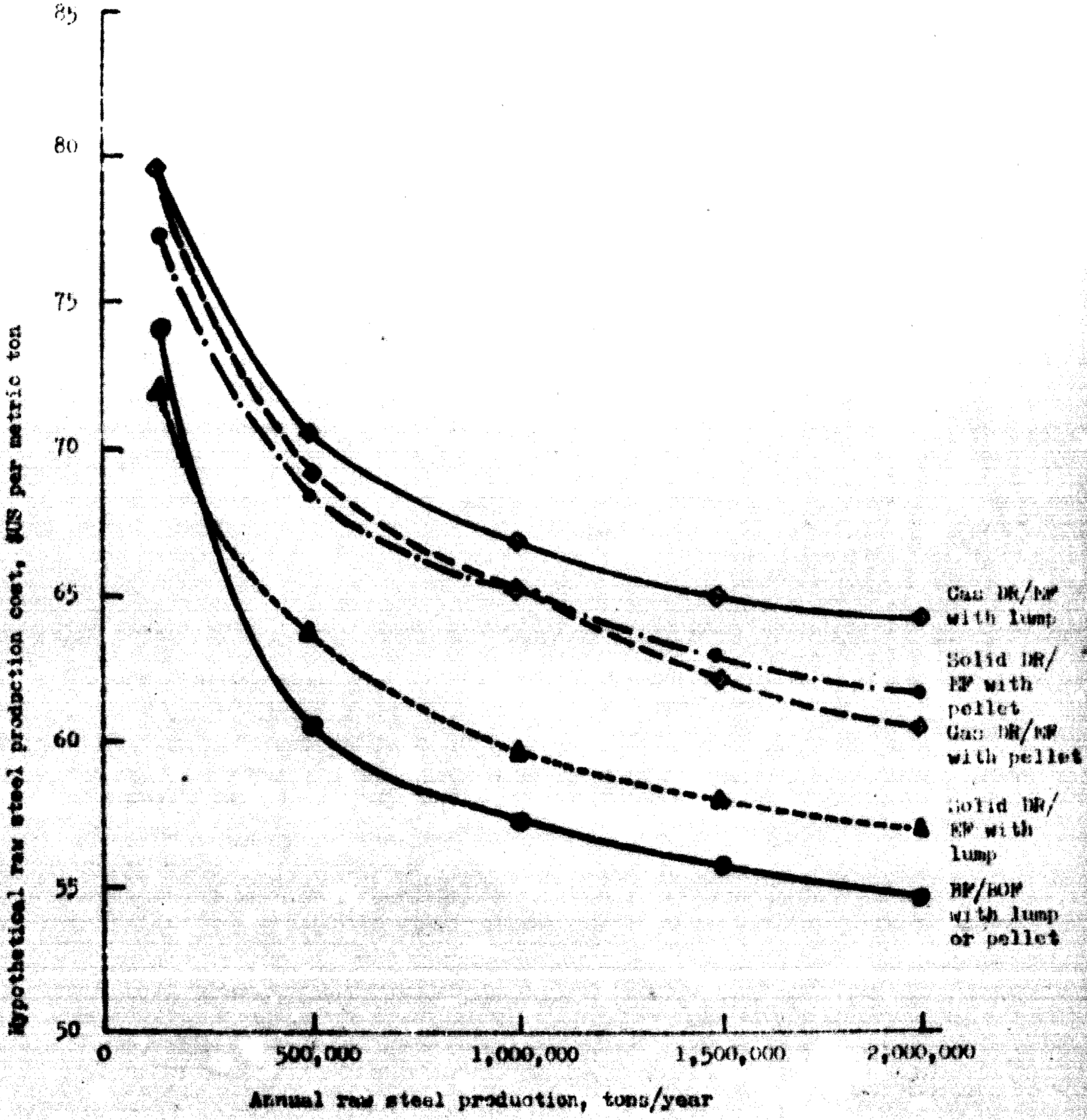

Figure II - Comparison of steel production routes (blast furnace + BOF and direct reduction + electric furnace) is greatly subject to the development of cooperative joint work programs between interested parties in the industrially-emergent and industrially-advanced countries, on government and corporate levels. Both sides have much to contribute for their mutual benefit.

From the side of the developing countries, there will be need for "support for efforts directed towards consistent policies for iron ore mining operation integration through further processing in exchange for important mining concessions on mutually acceptable terms". On the side of the developed nations, they will have to initiate "a lowering of tariff barriers and other deterrents to mineral product imports into their countries". On both sides, it will be necessary "to reduce the political content of negotiations that affect mineral operations in the developing areas". In summary, the mutuality of interest that must be served requires "the closest harmonious relationships between officials of the mining and steel companies and those of the mineral resource countries . . . to facilitate higher degrees of integration of iron-ore mining and processing operations in the developing countries".

In practical terms, both sides will have to work together so that "the transfer of know-how that marked the transition from run-of-mine to upgraded ore outputs will be extended to include metallized pellets".(29) The challenge of funding exists for all industry efforts and, in this case, may be offset by favorable returns on investment that usually may be anticipated. Finally, the deficiencies of adequate management personnel and trained labor staff will generally be resolved by the benefits which both producer and consumer of iron ore may receive from processing at the source in developing countries. Closely related motivations provide the basis for wholly or partially joint activities that combine the experience and needs of the developed areas with the resources and enthusiasm of the developing countries.

The quoted sections in the two preceding paragraphs are taken from a report released in 1967 by the United Nations Conference on Trade and Development. That study suggested that the current and forecast situations of the iron-ore mining and the steel industries made it then appropriate to recommend extension of iron-ore pretreatment practices and, more specifically, on-site oxide pellet production in the developing countries.(29) One may now judge, on the basis of actual experience some 5 years later, that the proposal was sound and beneficial to iron-mining and steel industry interests in both developed and developing countries.

The similar recommendation in this paper, urging further processing of iron ores in developing countries, through the stage of pre-reduced agglomeration, is a logical extension of that earlier suggestion.

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(29) The cited reference reads: " . . . extended to include oxide and later, metallized pellets." See "Prospects for Export of Processed Iron Ore from Developing Countries", by J.B. Miller for United Nations Conference on Trade and Development; January, 1967. Published as U.N. Document TD/B/C.2/29-April 17, 1967

SUMMARY AND CONCLUSIONS

Iron-ore processing and, to the extent it is pertinent, the transformation of the ore to iron and steel, is examined in this paper. The purpose is to define possibilities for expanding ore-processing operations in suitably endowed developing countries of the world as international trade in iron-bearing materials increases during the next 10 to 15 years.

The present high level of activity in the world market for iron ore and agglomerates is a relatively recent development. Before 1950, export shipments of iron ore from the iron and steel producing countries were comparatively small. In that year, a total of 32.7 million metric tons (1) of iron ore were imported by the industrially advanced countries, in particular by the European Economic Community countries (EEC)(2), the United States, and Japan. Ten years later, this figure was 130 million tons, and by 1970 a 7-fold increase over 1950 placed iron-ore imports at about 215 million tons; with the centrally-planned economies (CPE's) included, the world total equalled 250 million metric tons.

These considerable increases in iron-ore shipments were facilitated by explorations that uncovered and opened huge iron deposits, mostly in newly explored areas of Latin America, Africa, Australia, and Canada. The additional reserves were intended primarily for export to advanced steel-producing countries. Parallel to the development of new ore sources, a gradual shift to more highly beneficiated ore burdens was initiated at the iron-making furnaces. Demands for higher productivity were reflected in the iron-makers' insistence on better quality control of their raw materials. The advent of sintering, and later, pelletizing, eased the problem of fines at the mines and at the iron plants, so in the 1960's both agglomerating practices became established features of modern blast furnace operation. The technical and economic advantages gained from highly beneficiated and agglomerated iron burdens brought wide-spread preference for iron-ore agglomerates. The resulting improvements have been so impressive and the pressures for continued technological advances so insistent, that great interest is now focused on the next pretreatment step -- direct reduction, which will further "beneficiate" the ores before smelting.

Direct reduction processes fall into two groups; one using gas, and the other coal, as the reductant. At present, there are commercial

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(1) Unless otherwise indicated, "tons" refers to the metric ton of 2,204 lbs.

(2) In this case, limited to Belgium, the Federal Republic of Germany, France, Italy, Luxemburgh, the Netherlands, and the United Kingdom.

installations based on gases are operating in Mexico, West Germany, and the United States; other plants will soon go into production in Venezuela, Brazil, and Canada. The processes based on solid reductants have not yet reached a comparable stage of viability. When this is achieved, probably before 1975, the direct reduction development, which is already gaining momentum on the basis of the gaseous processes alone, will move forward at speeds reminiscent of the advent of oxygen-blown steelmaking in the 1960's.

All this is of great importance to many developing countries, expecially those with significant iron ore deposits. Some nations that have large natural-gas resources, like Algeria, which also has iron-ore reserves, and Iran, which can import them, already are potential candidates for direct reduction operations. But, a much greater number of nations, industrially advanced no less than developing ones, with reasonably priced coal (and little or no gas) are eagerly waiting for the solid reductant process breakthrough.

This development is one of the results of broad technological advances since 1950. These brought to the industry new sophisticated practices of iron-ore mining, processing, and pretreatment, and of a more efficient use of the resulting product. The consequent changes at the mines and in the steel plants were soon reflected in steady increases in global steel production and consumption. From a 300 million-ton level in 1959 to 400 million in 1963 and 500 million tons in 1967, world steel output reached nearly 600 million tons in 1970. The pattern is expected to continue to 735 million tons in 1975, 915 million tons in 1980, and over one billion tons by 1985. Noteworthy in this picture has been the emergence of Japan as one of the world's great steelmakers, accounting for 4% of the global output in 1955 and 16% in 1970. By 1985, Japan's production of raw steel is foreseen at nearly 180 million tons, nearly twice its tonnage output of 1970. Because Japan lacks iron ore, her leading position among the world's steel producers has stimulated and will help maintain large operations in the world's iron-ore centers.

The relative shares of older steel-producing countries have fallen considerably but their participations will level off during the 1970's and 1980's. The United States position, having declined from 39% in 1955 to 20% in 1970, will settle at around 16% of the world's total steel; Western Europe's decline as a steel producer from 29% to 27% is expected to level off at 24% after the 1970 decade; the Eastern Europe's proportion is foreseen as continuing at approximately one-quarter the global total.

The share of the developing countries — Asia with Japan excluded, Africa excepting the Republic of South Africa, and all of Latin America — has increased from 4% in 1955 to 8% in 1970. The rise is expected to increase to approximately 11% of the world total by 1985. Latin America, and expecially Brasil, will contribute strongly to this position.

In 1985, the developing countries' expected output of 116 tons of raw steel will represent 11% of a global forecast that is likely to exceed 1025 million tons. In that same year, these countries will account for some 375 million tons or 30% of a global ore production of about 1250 million tons. Considering that the iron-ore reserves of those countries are almost equal in magnitude to the deposits in the economically advanced nations, it would appear that the increased ore requirements of the 1980's will generate excellent opportunities for the developing countries to participate increasingly in the world's iron ore and steel activities.

This inference is supported by past developments and recent trends in those industries. During the coming 10 to 15 years, increased iron-ore mining and processing activities are expected. Extended on-site and near-site ore pretreatment and steel producing operations in the developing countries are also anticipated. In fact, the validity of the forecasts presented in this paper depends to a great extent on the successful completion of many large programs that will establish mining and beneficiation facilities, oxide pellet plants, prereduction units, and steel-producing installations in the developing areas.

The magnitudes of these facility additions are unprecedented, even for what is one of the world's largest industrial enterprises. To attain raw-steel production levels of over 1 billion tons a year, the iron-ore and steel industry capacities must be doubled, approximately, in a global program that will engage the full capabilities of both developed and developing countries. The following forecasts and observations, which are described in the paper that follows, become highly relevant to such developments in the iron ore and steel industry of the coming decade:

1. Global steel consumption is expected to increase to 915 million metric tons in 1980 and 1025 million tons in 1985 from 592 million tons in 1970. Approximately 29% of the total will be accounted for by the centrally planned economies. The share of the developing countries will equal about 10% of the worldwide total in 1980 and nearly 12% in 1985.

2. Known iron-ore reserves in the world total approximately 300,000 million metric tons and potential ore resources another 550,000 million tons. The centrally planned economies have about 115,000 million tons of reserves, with over 110,000 million tons in the USSR. The remainder is divided in the proportion of 40% in the developing country areas (Africa, Asia, and Latin America) and 60% in the industrially advanced market-oriented countries.

3. Iron-ore production increased from approximately 372 million to 753 million tons, worldwide, between 1955 and 1970. The developing countries produced 50 million and 216 million tons during those years. For 1975, 1980, and 1985, global iron-ore production figures are expected to equal 910 million, 1080 million and 1250 million tons. Outputs by the developing countries are estimated at 250 million, 310 million, and 380 million tons, or 27% to 30% of the world total, respectively, for those years.

4. Iron-ore trade, worldwide, which equalled about 320 million tons in 1970, may rise to as much as 420 million tons of crude ore in 1975 and 550 million tons by 1980.

5. Highly processed ores will continue to be in growing demand in the 1970's and 1980's. Globally, screened run-of-mine and direct shipping ores will increase from 298 million tons in 1970 to 395 million tons in 1985, but there will be a drop in percent from 39.5% to 31%. Sinter fines will also increase in terms of tonnage, from 346 million to 500 million tons, but proportionately this will be a decline from 46% to 40%. Oxide pellets will advance in terms of weight as well as percent, from 106 million tons to 231 million, and from 14.1% to 18.5%. Prereduced pellet use will not become significant until 1980. The 1970 demand for prereduced ore of nearly 3 million tons is expected to rise to 11 million tons in 1975, to more than 60 million tons in 1980, and to twice that amount by 1985.

6. Technology already exists that can accelerate on-site iron-ore processing in the ore-producing developing countries. Additional opportunities are available for extended on-site pretreatment of ores, including directly-reduced materials production at new and existing mines.

7. Directly-reduced iron ore is well-suited for use in iron-making and steelmaking. They offer metallized iron units to "sweeten" blast-furnace burdens that result in reduced coke rates and higher furnace outputs; improved steel-making operations in electric furnaces; an excellent low-residual scrap supplement; lowered fume and dust emissions; and potential use for small-level steel plant operations for local product manufacture in developing countries.

8. The technical and economic viability of direct-reduction processes based on gaseous reductant has already been demonstrated in commercial operations in the United States, Mexico, and West Germany.

9. There is a wide range of mutual benefits available to iron ore mining and steel plant interests in both developed and developing countries. The effective realization of such advantages depend on the establishment of joint cooperative programs and close harmonious relationships between representatives of the mining and steel companies on the one hand, and those of the mineral resource countries on the other.

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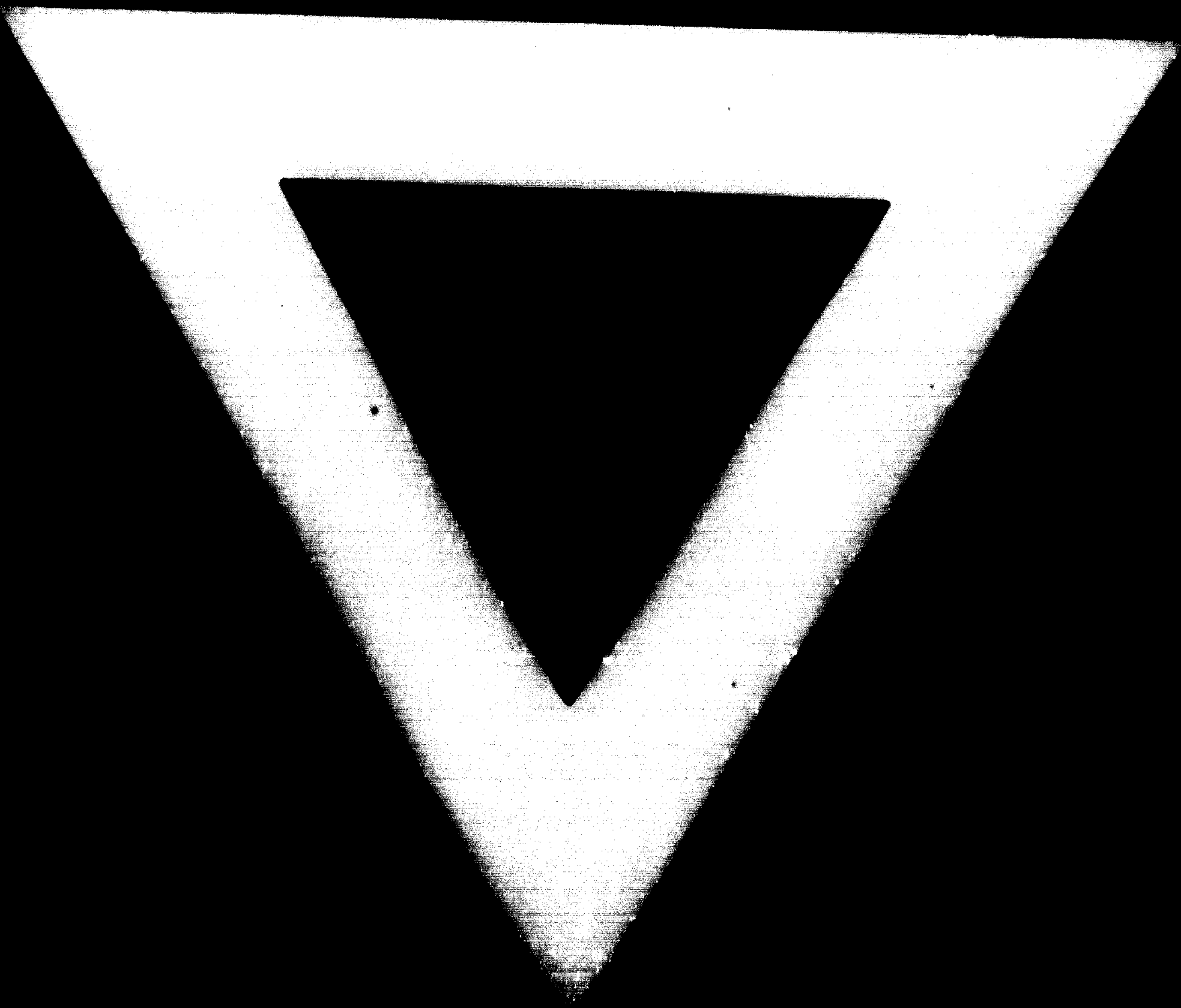

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