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BUREAU OF MINES
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Manganese Availability - Market Economy Countries: 1980's Perspective

By Joseph Coffman

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

kg Mn/t	kilogram manganese per ton	m^3	cubic meter
kg/t	kilogram per ton	mm	millimeter
km	kilometer	Mn	manganese
km^2	square kilometer	t	ton (metric)
lb	pound	t/hr	ton per hour
ltu	long ton unit	yr	year
m	meter		

FERROALLOYS

HCFeMn	High carbon ferromanganese	LCFeMn	Low carbon ferromanganese
MCFeMn	Medium carbon ferromanganese	SiMn	Silicomanganese

MANGANESE AVAILABILITY - MARKET ECONOMY COUNTRIES: 1980's PERSPECTIVE

By Joseph Coffman

ABSTRACT

There are 14 operations that supply 97% of the Market Economy Country (MEC) manganese and contain nearly all of its resources. Six mines account for about 70% of the production and 85% of the resources; there are no known resources that are economically close to those that are currently being mined. Costs (January 1989 dollars) of producing manganese concentrates from the operations evaluated are estimated to range from \$ 0.96 to \$ 1.86 per long ton unit (ltu or 22.4 lb) of contained manganese. Total MEC demonstrated resources evaluated amount to about 1.2 billion tons of in situ ore containing 474 million tons of manganese. Identified resources amount to about 1.8 billion tons of in situ material.

Key results of the study indicate the following:

1. The MEC supply of manganese will be from the currently mined resources well into the next century.
2. Centrally Planned Economy Countries (CPEC's) will be increasingly dependent on MEC manganese ore and concentrate in the future.
3. At the 1976 to 1987 demand increase rate, total MEC resource needed through the year 2000 would be about 282 million tons of in situ material.
4. Transportation and infrastructure support will continue to be major elements of production costs.

INTRODUCTION

This report is, in part, an update of Information Circulars IC 8978 (*2*)[1] and IC 8889 (*13*); however, this study emphasizes more the demand and supply aspects of the commodity.

Identified resources (proven plus probable plus inferred) are shown, but evaluated quantities are limited to those that are assumed as demonstrated (proven plus probable). Further, these demonstrated resources are all of current mining grade and are within the ore bodies now being mined. Also, it is assumed that the resources evaluated would contain at least 35% Mn and would be adaptable to the production of manganese ferroalloys.

The United States is totally dependent on imports for its supply of manganese ores and concentrates.[2] There is one operating smelter in the United States, which, for the last few years, has been smelting about 100,000 tons per year of ore from the U.S. strategic stockpile of manganese ore and returning the resulting ferromanganese to the stockpile.

The resource and availability setting has changed little since the previous report; there remain the same few major resource bodies that contain the long-term supply of manganese ore. This study includes the potential supply from 14 producing operations. Six of these alone account for about 70% of the MEC production capacity and over 85% of the demonstrated resources. No other potential ore sources are deemed close to being cost competitive to these deposits in the foreseeable future. U.S. deposits are mentioned only for comparison since they are low grade and have higher potential production costs (as much as eight times the cost of producing mines in other countries).

The Centrally Planned Economy Countries (CPEC's) are discussed only with respect to demand and supply, but not quantitatively for resources. The quality of their ores is decreasing, so the Market Economy Countries' (MEC's) deposits will undoubtedly be a future source of at least part of the supply for CPEC's as well.

Because of the remote location of the deposits, transportation and infrastructure will continue to be major elements of production costs.

Unless otherwise noted, metric units are used throughout the report.

COMMODITY OVERVIEW

Manganese is a vital element in industrial societies; virtually all steel contains some manganese. It is the 12th most abundant element in the Earth's crust and, thus, manganiferous occurrences are relatively widespread, although only a few deposits, worldwide, are of economic importance. Manganese is a relatively low-value commodity, of relatively abundant supply, and is used in larger quantities than other ferroalloy materials. More than 90% of all manganese produced is used in the ferrous and nonferrous metallurgical industries to enhance the metals' properties, such as strength and workability. The remainder is used mainly in the battery and chemical industries. Because of improvements in steelmaking processes, consumption of manganese per unit of steel has decreased in recent years.

Other elements can rarely be substituted satisfactorily for manganese on a cost-effective basis. No suitable substitutes have been found for metallurgical uses of manganese; only in chemical uses have substitutions been made.

Nearly all manganese resources are located at relatively great distances from the major consuming centers, such as Europe, Japan, and the United States, thus, shipping will remain a major part of production costs. Additionally, the producing mines are mainly in remote locations where all services (housing, health, and educational facilities, etc.) must be furnished to the personnel.

The manganese industry encompasses mainly separately owned concentrate and ferroalloy production facilities. Approximately 35% of the MEC manganese ferroalloys are produced in manganese concentrate producing countries, and about 20% of the concentrates are smelted by concentrate producing companies; the rest is sold to independent smelters. Thus, for a large majority of the industry, production of ore and that of ferroalloys is by independent industries. In total, there are some 14 mining operations that supply concentrates to about 60 to 65 smelters.

Concentrates are generally purchased through annual contracts from major suppliers, with some spot purchases for special purpose blending. Major concentrate producers normally handle their own sales; spot purchases are often done through brokers. Smelters in turn market ferroalloys to steelmakers, at times adjusting the product mix to fit changing market demands.

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[1] Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

[2] The terms "ores" and "concentrates" are sometimes used interchangeably, since "concentrates" are many times only crushed or washed raw ore.

The marketed ferroalloy products include:

Product	Approximate grade (%)
High carbon ferromanganese (HCFeMn)	Mn - 76% to 79%; C - 6% to-7%
Medium carbon ferromanganese (MCFeMn)	Mn - 81%; C - <1.5%
Low carbon ferromanganese (LCFeMn)	Mn - 85%; C - <0.5%
Silicomanganese (SiMn)	Mn - 60% to 65%; Si - 16% to 20%

There is no standard market price structure for manganese concentrates or ferroalloys. Concentrate and alloy prices can vary independently, depending on their own specific characteristics and markets for particular types of products. Most mines produce several concentrates with different physical and chemical characteristics. Thus, published prices are an interpretation of a combination of prices paid for a mix of concentrate products. A purchase contract for concentrates from a single mine may include several individual prices for individual concentrates. Prices for some concentrates in late 1988 were over $2/ltu, (long ton unit, or 22.4 lb contained manganese) and some HCFeMn sales brought over $600/lt, while early 1988 prices were in the order of $1.40/ltu for concentrate and $400/lt for HCFeMn.

TECHNOLOGY

The technology of the manganese industry is relatively simple; in many cases mining is on continuous and relatively undisturbed horizons, and beneficiation consists mainly of sizing and washing. Manganese is relatively easily smelted compared to other ferroalloys, although several different concentrates generally must be blended to obtain an appropriate mix of constituents.

Manganese ore is mined using both open pit and underground methods. Of the 14 operations evaluated, there are basically 7 of each type; the two areas evaluated in India have many small-scale hand operations, one area mainly open pit and the other mainly underground. Open pit mines account for over 70% of the production.

In open pit mines, stripping ratios are generally in the order of 1:1 to 1.5:1. Where there is a small amount of surface cover (5 to 6 m) the ore is normally soft, which usually results in the production of more fine material (minus 6 mm) and lower beneficiation recoveries. In order to be usable as smelter feed, ore or concentrate generally must be in the lump form (plus 6 mm).

Except for one modified sublevel operation in Mexico, underground mining is mainly by room and pillar methods. Most of the manganese ore horizons are either flat-lying or slightly dipping and show relatively little affect from folding and faulting. The enclosing rocks are generally competent and require little support.

Concentration of manganese ore consists mainly of crushing, screening and washing, which removes much of the barren clay material and also the fine manganese ore (minus 6 mm). The methodology of a few mines involves using heavy media to recover some minus 6 mm-plus 1 mm material; this generally works if the ore is high in free silica. Most manganese ore fines, though, are discarded (generally stockpiled separately from clay-type waste); manganese recoveries are generally 60% to 70%.

The grade of the concentrates generally ranges from about 38% to 51% Mn (some sintered ore may reach 56% Mn); the grade preferred by the smelters is 48% Mn with a Mn:Fe ratio of 7:8. Also, the content of other constituents, such as alumina, lime, silica, phosphorus, and alkalies, and the physical character of hardness and particle size are important. The economics of the manganese industry does not allow for sophisticated beneficiation methods that will supply a unique smeltable concentrate. What is available to the smelters is essentially a variety of crushed and washed "raw ores," each with its own character, few of which can be smelted efficiently by themselves, which necessitates the blending of several concentrates to obtain a proper smelter feed.

Sintering is used in a few mining operations, to fuse the fine material into usable lump. Currently, there are major sintering plants at three locations: (1) Bell Bay, Tasmania, 250,000 t/yr; (2) Mamatwan Mine, South Africa, 500,000 t/yr; and (3) Santana, Brazil, 50,000 t/yr. Other smaller sinter plants are located at various smelters, particularly in Japan; however, many of these are operated intermittently to process fines for the particular smelter. Including all of these plants, total MEC sintering capacity could be in the order of 1.5 million t/yr. Sintering normally increases the concentrate grade by about 6% by burning off carbonaceous material.

The Bell Bay plant has been in operation since 1968 to sinter the higher grade fine material produced at the Groote Eylandt mine. The sinter can contain as much as 56% Mn. The company is currently contemplating another sinter plant to be located at the mine site.

The South African sintering plant began production in 1988, which increased the manganese grade of the fines from about 38% to 44% in the sinter. The ore is quite hard, resulting in about 30% of material being produced as fines in the crushing process (*9*). A heavy media plant is planned for the future to further upgrade the sinter feed and the resulting sinter. The company is also contemplating increasing the sinter capacity by constructing a separate cooling facility, so that the entire sinter machine could be used for sintering.

The Santana sintering operation is a recent conversion of a sinter plant which was previously used in a pellet operation. The plant could be increased to a 100,000 t/yr capacity.

Assuming 30% of the ore feed being as usable fines generated during processing as an overall industry average, there could be another 2 to 3 million t/yr of fine material potentially available for sintering in the MEC's.

Nodulizing is used at the Molango, Mexico, operation to produce manganese oxide from a manganese carbonate mineral ($MnCO_3$) by driving off the carbon dioxide (CO_2) in a rotary kiln. A similar plant was built in Ghana in 1982 but has never operated. Also, batch sintering is done at Morra do Mina, Brazil.

Both sinter and nodules enhance smelting. Among their advantages are their compact physical character, which inhibits bridging in the furnace charge, and their high electrical resistivity, which increases efficiency in the furnace.

As stated previously, there are some 60 to 65 ferromanganese smelters in operation in the MEC's. An accurate count is not possible, since some of the plants are sometimes used to smelt other ferroalloys. A list of these smelters, either dedicated to or available for production of manganese ferroalloys, is shown in Appendix A.

Manganese ferroalloy smelters predominantly use submerged arc electric furnaces, although considerable HCFeMn is produced in blast furnaces. Currently there are four blast furnace facilities operating in the MEC's. One of these, of recent construction in Japan, was built to reduce energy costs through the use of coke, rather than electrical energy, as a heat source (*14*). Smelting practices vary between operators, but the general method is to produce an HCFeMn alloy and a high Mn content (28% to 30% Mn) slag, which is used to produce SiMn. Ideally, the product ratio is about 600 kg of SiMn for every ton of HCFeMn produced. If the refined alloys are produced (MCFeMn and LCFeMn), the SiMn is generally used as feedstock. Overall manganese recoveries in smelting are generally 91% to 92%. Blast furnaces generally do not produce SiMn; the slag produced is sold to other plants as a feedstock for SiMn production.

Operations of individual smelters are usually unique, depending on the operational practices of a particular management, type of feed materials available, and their market niche for products. Certain plants may produce an excess amount of SiMn, or produce only SiMn, such as at Kvinesdal, Norway, and Dunkirk, France. Some may predominately produce refined products of MCFeMn and LCFeMn, such as at Sauda, Norway.

Most plants today are equipped with closed furnaces, although there are still a number of open furnaces in operation. These are normally smaller and of an older generation; some are used as refining furnaces to produce MCFeMn and LCFeMn.

Advances in steelmaking have reduced the amount of manganese ferroalloys used per ton of steel in recent years. Newer techniques include improved process control, desulfurization at the hot metal or ladle stage, and more efficient blowing methods that reduce manganese losses through oxidation.

There has been an increasing usage of SiMn in steelmaking. SiMn is preferred in many of the minimills, since it contains the right proportions of manganese and silicon and can have a low carbon content.

Some Japanese steelmakers are now predominantly using direct additions of ore to the converter, partially replacing the use of HCFeMn. The manganese recovery is much less (probably less than 50% for all steels), compared to 80% to 90% using the HCFeMn.

PRODUCTION

ORE AND CONCENTRATES

World manganese ore and concentrate production for the years 1976-1987 are shown in table 1. In the MEC's during this period, 28 countries recorded production; however, 14 of these were relatively insignificant, especially after 1982. Four countries (Australia, Brazil, Gabon, and the Republic of South Africa) currently produce a little over 82% of the MEC total; by including India and Mexico the total is nearly 97%. India's production statistics are somewhat deceptive, however, since over one-half of the production is low grade ferruginous manganese ore and is generally not used for ferroalloy production.

The United States is shown separately, since it did not produce any manganese ore. In fact, the ferruginous manganese shipments in the United States (10% to 35% Mn) ceased after 1984.

Table 1.—World manganese ore and concentrate production, 1976-87
(thousand tons, gross weight, unless otherwise noted)

Country	Mn %	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Market economy:													
Australia	37-53	2,154	1,389	1,241	1,723	2,019	1,448	1,132	1,370	1,848	2,003	1,649	1,853
Brazil	38-50	1,696	1,515	1,916	2,258	2,281	2,042	1,300	2,092	2,693	2,699	2,699	2,404
Gabon	50-53	2,216	1,850	1,710	2,299	2,146	1,487	1,512	1,857	2,119	2,339	2,510	2,404
Ghana	30-50	312	292	316	272	252	225	132	173	268	290	280	244
India	10-54	1,834	1,865	1,619	1,755	1,645	1,526	1,466	1,281	1,130	1,240	1,300	1,302
Japan	24-28	142	126	104	89	80	87	62	75	62	21	6	–
Mexico	39	453	487	523	493	447	578	509	334	476	396	459	385
Morocco	50-53	117	114	126	136	132	110	94	73	59	44	36	43
South Africa, Republic of	30-48	5,451	5,047	4,354	5,182	5,694	5,038	5,215	2,885	3,048	3,600	3,719	2,891
Other[1]	NAp	593	300	262	199	193	134	213	42	79	45	44	42
Total MEC		14,968	12,985	12,171	14,406	14,889	12,675	11,635	10,182	11,782	12,677	12,702	11,568
Centrally planned economy:													
China	20	1,000	1,134	1,497	1,596	1,596	1,596	1,596	1,596	1,596	1,596	1,596	1,596
U.S.S.R.	35	8,635	8,590	9,056	10,242	9,751	9,152	9,823	9,878	10,068	9,887	9,343	9,343
Other[2]	NAp	172	155	155	125	132	174	183	182	178	167	168	169
Total CPEC		9,807	9,879	10,708	11,963	11,479	10,922	11,602	11,656	11,842	11,650	11,107	11,108
Grand total		24,775	22,864	22,879	26,369	26,368	23,597	23,237	21,838	23,624	24,327	23,809	22,676
United States[3]	10-35	183	177	263	195	140	138	15	10	62	–	–	–
Do.	5-10	49	18	20	24	18	20	14	20	18	18	13	20

NAp Not applicable.

[1] Includes Bolivia, Chile, Egypt, Greece, Indonesia, Iran, Italy, Republic of Korea, Pakistan, Philippines, Thailand, Turkey, Yugoslavia, and Zaire.

[2] Includes Bulgaria, Hungary, and Romania.

[3] United States not included in totals since it did not produce any manganese ore (plus 35% Mn).

Source: Bureau of Mines Yearbook, various years, manganese chapter.

In the CPEC's, the U.S.S.R. is the main source, accounting for about 84% of the total concentrates produced; however, most of these concentrates would not be marketable by MEC standards because of their low manganese grade. In gross weight, the ore and concentrate production is about evenly divided between MEC's and CPEC's. In terms of contained manganese, though, MEC production in 1987 amounted to about 60% of the world total. Again, these percentages can be somewhat misleading in terms of the manganese used in ferroalloy production, since the CPEC's use much more of their manganese as an additive in the iron blast furnaces than do the MEC's.

FERROALLOYS

Table 2 lists the MEC and CPEC manganese ferroalloy production during the years 1976-1987. In this period, a total of 24 countries were reported as producing manganese ferroalloys in some form. In 1987, nine countries accounted for about 76% and 79% of FeMn and SiMn, respectively.

The data show that the production of SiMn is increasing, compared to FeMn. In 1976, SiMn amounted to about 22% of the total ferroalloy production, while in 1987, this production was a little over 30% of the total.

Production of manganese ferroalloys in 1987 was less than in 1976, since demand had not fully recovered from the 1982 recession. The two largest producers in 1976, Japan and the United States, suffered the largest decline, about 57% and 75%, respectively. This resulted in shutdowns of a number of smelters in both countries. The United States has one operating smelter at Marietta, OH, and one at Calvert City, KY, that produce intermittently.

Table 2.—World managanese ferroalloy production, 1976-87 (thousand tons)

	1976		1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987	
Country	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn
Market Economy:																								
Argentina	24	6	36	6	25	10	37	16	35	15	34	14	24	15	25	14	24	14	24	7	23	8	22	12
Australia	50	15	71	24	95	–	86	20	86	19	85	19	54	30	49	20	76	31	69	27	58	23	52	43
Belgium	84	–	55	–	87	–	90	–	85	–	90	–	85	–	87	–	95	–	90	–	87	–	87	–
Brazil	99	63	129	75	118	106	133	128	141	134	128	122	122	162	103	179	106	186	135	180	164	178	155	180
Canada[1]	80	–	60	–	70	–	41	–	86	–	109	–	138	–	107	–	116	–	118	–	126	–	128	–
France	365	12	358	21	390	19	440	13	470	21	315	9	331	30	269	33	328	34	333	24	274	22	273	22
Germany, Federal Republic	280	–	225	–	225	–	223	–	225	–	233	–	219	–	147	–	264	–	193	–	222	–	211	–
India	176	–	193	10	220	3	189	5	162	5	209	9	158	14	151	3	122	32	163	1	160	1	173	1
Italy	78	42	75	40	90	43	89	54	83	45	81	54	74	58	62	37	51	73	17	64	25	60	26	60
Japan	632	373	527	334	455	303	603	299	569	310	570	283	538	269	389	222	485	233	442	217	359	149	332	92
Korea, Republic of	29	–	36	–	47	–	53	–	54	–	64	–	60	–	53	–	59	–	62	–	54	–	58	–
Mexico	54	17	100	27	107	34	123	31	125	31	125	30	135	32	140	42	161	42	153	39	156	61	162	80
Norway	348	169	244	127	273	133	337	184	296	168	224	198	203	216	282	195	285	281	215	242	190	260	190	261
Portugal	55	2	55	5	78	15	75	15	74	17	73	18	45	24	40	18	46	24	42	25	20	10	26	16
South Africa, Republic of	350	22	310	22	330	22	560	45	500	60	450	50	444	36	145	145	190	190	331	237	337	272	345	275
Spain	133	91	141	63	134	109	148	119	120	123	92	63	87	71	85	70	85	70	86	70	86	70	90	70
United Kingdom	122	–	69	–	69	–	137	–	52	–	91	–	61	–	96	18	88	–	87	–	85	–	80	–
United States	438	117	303	109	248	129	288	150	171	171	175	157	108	63	80	NA	155	NA	140	NA	106	NA	103	NA
Yugoslavia	–	–	54	9	36	28	45	9	44	28	54	29	39	20	40	26	50	38	47	36	45	40	40	66
Other[2]	18	–	14	–	15	–	21	1	20	2	19	–	40	23	63	18	42	23	43	31	42	31	28	59
Total MEC	3,415	929	3,055	872	3,112	954	3,718	1,089	3,398	1,149	3,221	1,055	2,965	1,063	2,413	1,040	2,828	1,271	2,790	1,200	2,619	1,185	2,581	1,237
Centrally planned:																								
Bulgaria	33	–	30	–	28	–	28	–	28	–	34	–	34	–	30	–	22	–	30	–	32	–	31	–
China	191	–	233	–	309	–	341	–	590	–	526	–	472	–	490	–	490	–	490	–	599	–	653	–
Czechoslovakia	70	–	100	–	100	–	100	–	100	–	100	–	95	–	94	–	87	–	94	–	92	–	92	–
German Democratic Republic	80	–	89	–	80	–	76	–	70	–	68	–	63	–	64	–	63	–	63	–	68	–	68	–
Korea, North	40	–	57	–	66	–	66	–	70	–	70	–	70	–	70	–	70	–	70	–	70	–	70	–
Poland	162	–	174	–	166	–	163	–	166	–	160	–	123	–	133	–	138	–	129	–	135	–	135	–
Romania	–	–	–	–	–	–	–	–	66	31	70	33	76	36	80	38	87	41	80	39	82	40	81	39
U.S.S.R.	1,216	26	1,252	30	1,285	30	1,460	30	1,521	32	1,080	32	1,000	32	1,049	170	1,150	180	1,225	190	1,250	200	1,250	200
Total CPEC	1,792	26	1,935	30	2,034	30	2,234	30	2,611	63	2,108	65	1,933	68	2,010	208	2,107	221	2,181	229	2,328	240	2,380	239
Grand total	5,207	955	4,990	902	5,146	984	5,952	1,119	6,009	1,212	5,329	1,120	4,898	1,131	4,423	1,248	4,935	1,492	4,971	1,429	4,947	1,425	4,961	1,476

NA Not available.

[1] Includes SiMn.

[2] Includes Austria, Chile, Taiwan, Venezuela, Zimbabwe.

Source: Bureau of Mines Yearbook, various years, ferroalloys chapter.

GEOLOGY

Manganese deposits are classified into four geological types: hydrothermal, residual, metamorphic, and sedimentary (*15*, pp. 10-14). Hydrothermal manganese deposits are normally made up of carbonates and oxides of manganese minerals along with other hydrothermal minerals such as barite, fluorite, and sulfides.

Residual deposits are formed near the surface by weathering processes. Large deposits of economic significance include the Serra do Navio deposit in Brazil, Moanda in Gabon, Nikopol' and Chiatura Basins in the U.S.S.R. and several occurrences in Australia and India.

Metamorphic occurrences are generally in the form of low-grade silicates and rarely if ever have any economic value.

Sedimentary manganese deposits contain the largest portion of world economic manganese. These deposits are subdivided into several subclasses as shown below:

1. Volcanogenic deposits are those in which the manganese can be related directly or indirectly to volcanic sources. The ore at the Magnitogorsk area in the U.S.S.R. and Nsuta Mine in Ghana are considered to be in this class.

2. Nonvolcanogenic sedimentary deposits include those where the manganese is not related to any volcanic source. The more important manganese deposits of this type include Groote Eylandt in Australia, the Morro do Urucum area in Brazil, and the Maharashtra-Madhya Pradesh area in India.

3. Metasedimentary manganese deposits associated with iron formations are identified in Brazil and South Africa. The iron formation units are extensive and occur over relatively great distances; however, the associated manganese beds within these formations vary in thickness and continuity.

4. Ocean floor nodules cover vast areas in the Pacific, Atlantic, and Indian Oceans. The nodules are found at all depths in the oceans, but higher grades are usually found within the deeper basins, at great distances from land areas.

RESOURCES

There have been a number of worldwide manganese resource compilations published in recent years. Because of apprehension over manganese supply interruption in the late 1970's, resource studies proliferated at that time. At first, the nature of the reports stressed alternate sources, chiefly deep sea nodules. This in turn was countered by a number of reports directed towards showing the abundance of land-based resources, that could produce an ample supply even if the supply from any one country was interrupted. Since that period, the manganese resource data generation has been somewhat static. Production during the interim has generally made little change in overall resource quantities. In most cases, exploration has identified sufficient ore to compensate for that extracted by production.

A world study of resources was completed by the U.S. Geological Survey in 1973 (*9*), and in 1979 the Geological Survey and the U.S. Bureau of Mines presented another world resource compilation (*7*). Also, these agencies jointly developed a classification system defining various categories of resources (*26*). This is shown diagrammatically in figure 1. In 1979, the South African

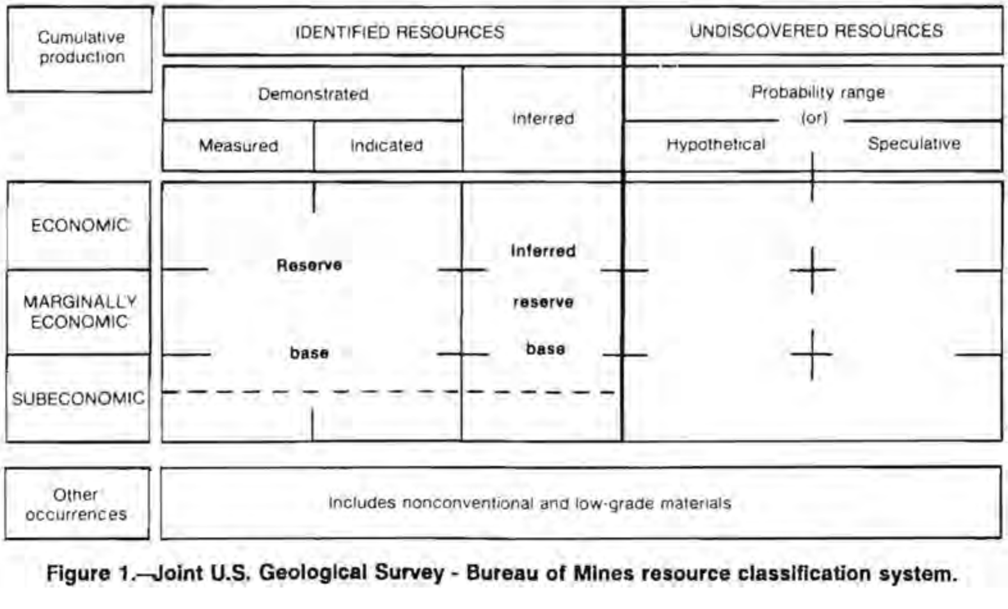

Figure 1.—Joint U.S. Geological Survey - Bureau of Mines resource classification system.

Minerals Bureau also published a relatively comprehensive estimate of world manganese resources (*10*). Probably the most comprehensive world manganese resource study was presented by the National Materials Advisory Board in 1982 (*15*). A compilation in 1984 summarized data from previous studies (*8*).

Unfortunately these studies do not uniformly categorize resources by the same standards. Resources have been classified in a number of separate designations, such as measured, indicated, inferred, other, conditional, hypothetical, submarginal, etc. These designations essentially describe the same in situ resources and originate basically from the same data sources. However, what is known is that the bulk of the resources are contained in a few huge deposits, which are currently being mined, and that there are no other known manganese resources of the magnitude of these particular ore bodies.

Resources depicted as significant for this study as of January 1989 are listed in table 3. The location of the deposits is shown in figure 2. The resources, as shown in the table, are an update of the previous study; however, they are arbitrarily restricted to demonstrated resources (proven plus probable) that are of current mining grade and are all at producing operations. Further, all are explored to the extent of defining the grade preparatory for mining. Identified resources are defined as including inferred tonnages, which would require additional exploration and development for mining. U.S. resources are not shown because of their low grade and potentially high extraction costs.

Table 3.—Market economy country mine and deposit data

Country and mine	Owner and/or operator	Map index[1]	Type of operation[2]	1988 capacity (10^3 tons)	Resources (10^6 tons)		
					Demonstrated		
					In situ	Contained manganese[3]	Identified (in situ)
Australia: Groote Eylandt	BHP-Utah International	10	OP	2,400	156	62	397
Brazil:							
Azul	Companhia Vale do Rio Doce (CVRD)	3	OP	1,000	65	27	65
Mato Grosso do Sul	(4)	4	UG	150	30	14	50
Serro do Navio	Industria e Comercio Minerios SA (ICOMI)	2	OP	1,000	15	15	15
Total				2,150	110	56	130
Gabon: Moanda	Cie Miniere de l'Ogooue (Comilog)	6	OP	2,500	100	44	360
Ghana: Nsuta	Ghana National Manganese Corp.	5	OP	300	15	5	30
India:							
Maharashtra-Madhya Pradesh area	Manganese Ore India, Ltd.	8	OP/UG	350	23	9	33
Keonjhar area	Various owners	9	OP	300	5	2	30
Total				650	28	11	63
Mexico: Tetzintla	Compania Minera Autlan	1	OP/UG	500	34	9	100
South Africa, Republic of:							
Gloria	Associated Manganese Mines of South Africa, Ltd. (AMMOSAL)	7	UG	600	30	12	30
Mamatwan	SAMANCOR, Ltd.	7	OP	1,200	400	152	400
Nchwaning	AMMOSAL	7	UG	1,000	100	44	100
Wessels	SAMANCOR, Ltd.	7	UG	1,200	180	79	180
Total				4,000	710	287	710
Grand total				12,500	1,153	474	1,790

[1] Refer to figure 2.

[2] Type of operation: OP open pit, UG underground.

[3] Numbers differ from table 4 due to divergent cutoff levels.

[4] Includes Santana and Urucum Mines, owned by Companhia Paulista de ferro Ligas and CVRD, repectively.

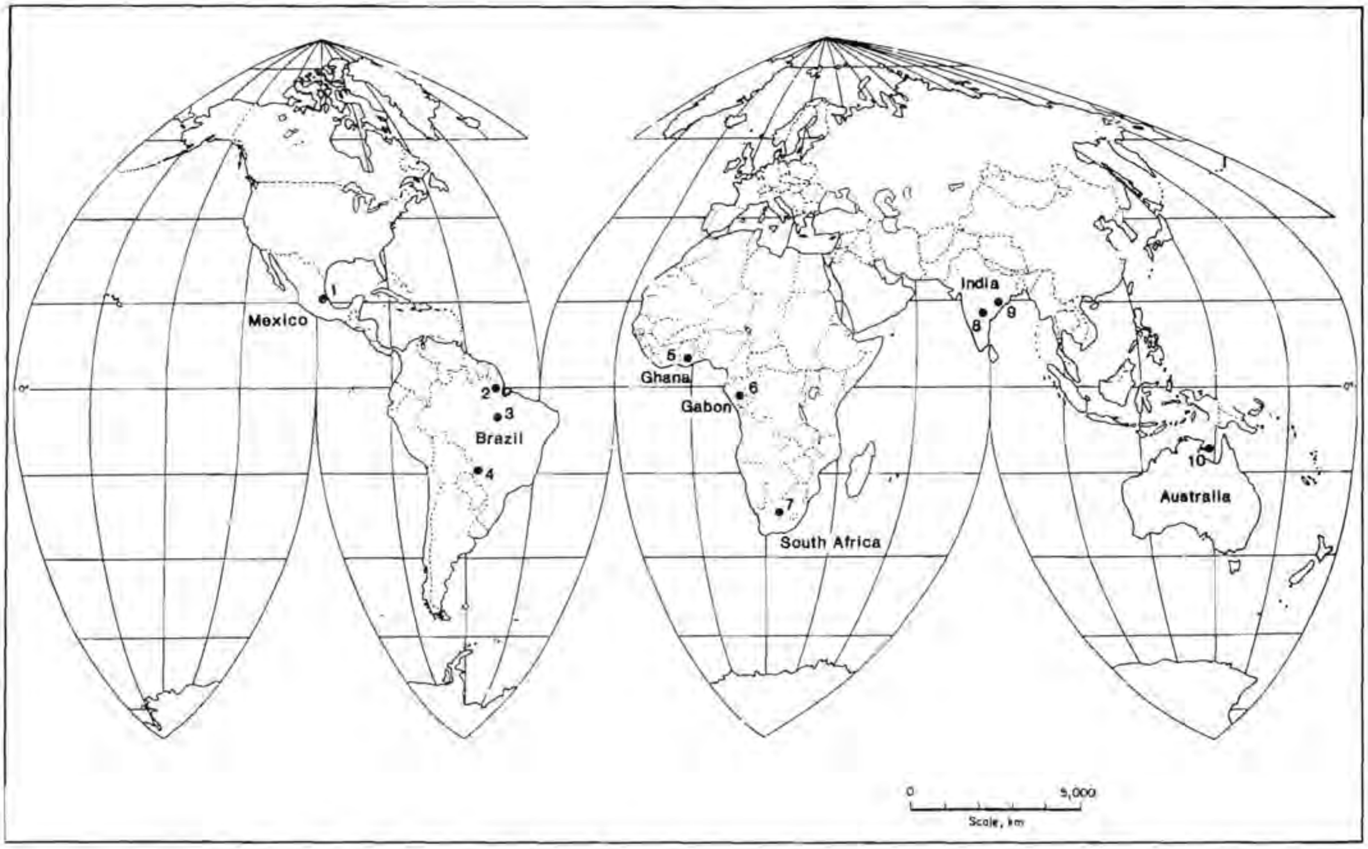

Figure 2.—Location of Market Economy Country manganese deposits.

Available world resource quantities have not changed significantly for a considerable length of time. Known resource bodies will continue to supply world manganese demand for many years. The major ore bodies in South Africa, Gabon, and Australia each have demonstrated and identified resources of several hundreds of million tons; with capacities ranging from about 2.5 to 5.0 million tons per year, they can produce for many years. Exploitation of the total identified resources would require additional exploration and development work and possibly more complex beneficiation processes to produce the same quality of concentrates. This aspect, however, is likely to be far in the future and will not be addressed by the industry until at least well after the year 2000.

The resource summaries, portrayed in the various Bureau of Mines reports, such as the Mineral Commodity Summaries (*21, 22*) are adequately shown in accordance with their own criteria. A summary of the Mineral Commodity Summaries 1990 world resources (Reserve Base), in terms of contained manganese, is shown in table 4. The CPEC resources are shown to portray their relative position with respect to those of the MEC's.

Table 4.—World manganese reserve base

Country	Contained manganese [1]
Market economy:	
Australia	154
Brazil	59
Gabon	163
India	25
Mexico	9
South Africa, Republic of	2,630
Total MEC	3,040
Centrally planned economy:	
China	29
U.S.S.R.	454
Total CPEC	483
Grand total	3,523

[1] Numbers differ from table 3 due to divergent cutoff levels.

Source: Bureau of Mines, Mineral Commodity Summary 1990, p. 107 (*22*).

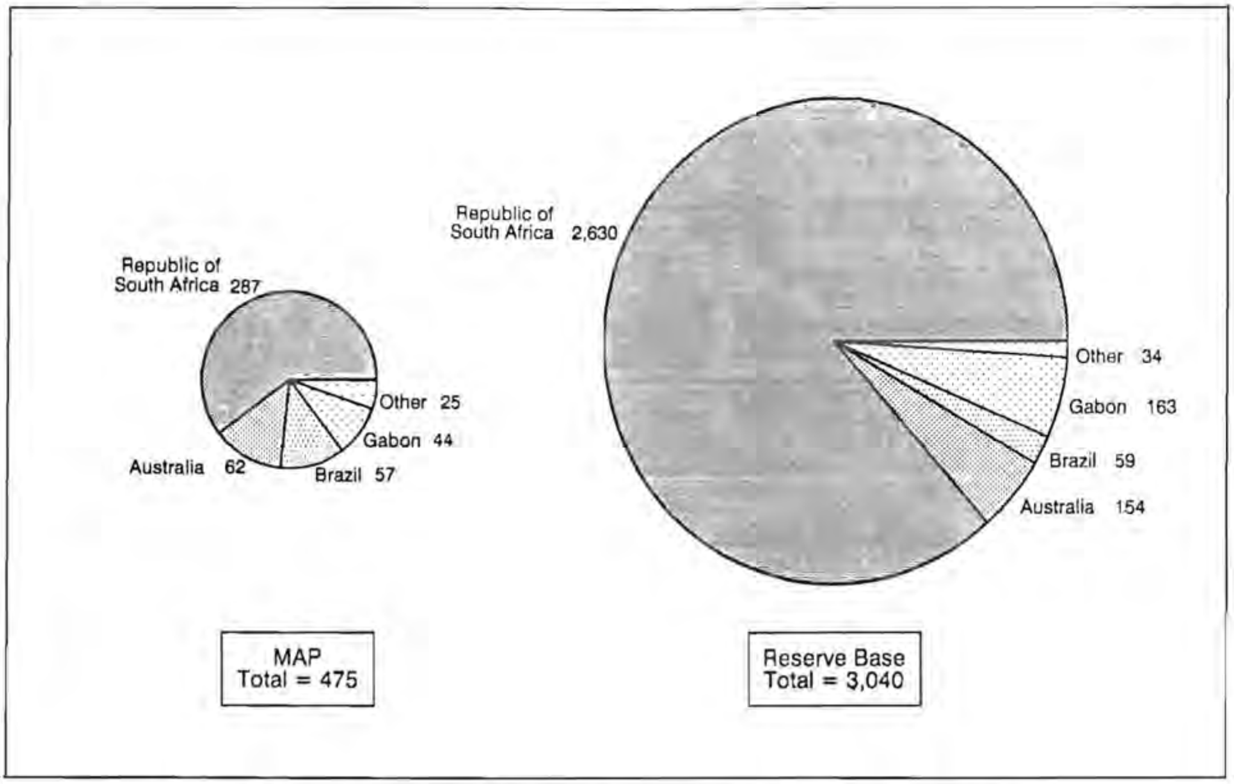

Figure 3.—Comparison of MAP and Reserve Base MEC manganese resources. (Quantities in million tons contained manganese).

In terms of in situ ore and contained manganese, the MEC's have about 80% and 87% of the total, respectively. This, however, does not portray the full resource perspective, since, as stated previously, many of the CPEC deposits would not be able to produce marketable concentrates by MEC standards.

A comparison between the resources used in this Minerals Availability Program (MAP) study and the Reserve Base numbers for the MEC's are shown in the two diagrams of figure 3. Here the principal differences are in Australia, Gabon, and the Republic of South Africa. In Australia, the value used in this study represents the resources fully delineated as to nodular, massive, siliceous, etc. In Gabon, only the currently mined Bangombe Plateau ore body resources are used. In the Republic of South Africa, this study uses ore bodies of current mining grade (to 38% Mn), whereas the Reserve Base represents material to 30% Mn.

ALTERNATE SOURCES

Deep sea nodules have been suggested as a long-term manganese supply that could be exploited by the United States at some future time. The National Defense Stockpile could also be used for a short-term supply in time of national emergency. U.S. deposits are also considered as an alternate source because of their low grade.

SEA NODULES

Manganese nodules are widespread on the sea floor, particularly in deeper sections. The composition of these nodules ranges from 1.8% to nearly 34% manganese and are associated with appreciable amounts of other valuable metals including cobalt, nickel, copper, and molybdenum. Although manganese comprises the major metallic constituent, cobalt, nickel, and copper constitute the metals of primary economic importance.

Apparently the most promising area is in the Pacific Ocean, southeast of the Hawaiian Islands between the latitude and longitude of N 6° to 20° and W 110° to W 180°. The average composition of nodules is estimated at 24.6% manganese, 1.28% nickel, 1.16% copper, and 0.23% cobalt (*27*). Huge quantities of resources have often been suggested, but exploration has been on a broad scale, and has not delineated specific resource areas that may be applicable to mining.

Technology necessary for mining and processing sea nodules has been under research and development for many years. The major problems associated with ocean mining are the technical ones, raising the manganese nodules from the seabed to a surface vessel and producing a marketable concentrate from low-grade material, and the legal ones associated with mining in international waters.

STOCKPILE

The National Defense Stockpile is a Government inventory system to meet essential military defense and civilian requirements in an emergency situation. It is not designed to control market prices or remedy short-term supply disruptions.

At the end of 1987, private inventories carried about 426,000 tons of all types of manganese ore, and the Government stockpile contained about 1.9 million tons and 834,000 tons of stockpile-grade and non-stockpile grade metallurgical ore, respectively (*25*, 1987, p. 2).

During 1984-1988, a total of about 163,000 tons HCFeMn has been produced from the ore stockpiles; as of Oct. 1, 1988, the manganese ferroalloy stockpile consisted of:

Manganese Ferroalloy	Thousand tons
HCFeMn	687
MCFeMn	26
SiMn	21

U.S. DEPOSITS

U.S. deposits are categorized as "alternate sources" because of their low grade of about 9% Mn (weighted average) and their potentially high recovery costs, which were estimated in an earlier study (*13*) and range from \$9.50/ltu to \$17/ltu (updated to 1989 dollars). A list of the deposits, with their associated estimated recoverable quantities, is shown below (million tons contained manganese):

Property, location	Estimated recoverable resources
Hardshell Mine, AZ	<1
Maggie Mine, AZ	<1
Maple/Hovey Mt., ME	15
North Aroostook Dist., ME	4
Cuyuna N. Range, MN	3
Butte Dist. Emma Mine, MT	<1
Three Kids, NV	<1
Sunnyside, CO	2

It should be noted that the beneficiation processes proposed for these deposits have only been bench-tested; that is, there is no proven commercial process for the U.S. material. Therefore, costs may be higher, and recoverable tonnages may be lower than estimated.

OPERATIONAL DATA

Operations and resources were discussed in some detail in the earlier report (*2*); the bulk of the manganese is still produced at the same operations, and there has been little change in resource quantities. The following is a summary of current operations including additional data that have become available since the last study. For deposit locations see figure 2.

AUSTRALIA

Manganese operations in Australia include the Groote Eylandt Mine, located on Groote Eylandt in Northern Territory, and the Bell Bay, Tasmania, FeMn smelter and sinter plant. These facilities are operated, respectively, by Groote Eylandt Mining Co., Ltd. and Tasmanian Electro Metallurgical Co. Pty. Ltd., both subsidiaries of BHP-Utah International of Australia. Mine operation began in 1966 and currently has a capacity of about 2.4 million t/yr of concentrate; roughly 2 tons of ore are required for a ton of concentrate.

Resources have been reported through the years under various criteria. In the previous report the quantity used was 305 million tons of demonstrated ore at 41% Mn and an additional 110 million tons of inferred ore (*2*, p. 8); however, more recently the quantities were expressed as about 200 million tons of each demonstrated and inferred ore (*17*). The 156 million tons of ore used in this report is limited to that which has been delineated as to massive, pisolitic, and siliceous (*1*). Additional resources (see table 3) are considered to be inferred.

Mining is by open pit with several pits being worked simultaneously for grade control; stripping ratio is about 1.5:1. Overburden is generally soft and is used for tailings dam construction and backfill in mined-out pits; topsoil is stockpiled for revegetation of mined areas. Massive ores normally are blasted, while pisolitic horizons can usually be excavated with bulldozers and loaders. Siliceous ore generally occurs at the base of the ore horizon. Ore is loaded by backhoes and truck hauled an average distance of about 8 km to the concentrator.

Mining is on tribal land, and, thus, environmental requirements are quite strict. Mined areas must be revegetated, and only 2.59 km^2 of land can be disturbed by mining at one time.

Beneficiation is essentially crushing, screening, and washing with a heavy media circuit to remove free silica from some of the feed. The heavy media circuit was improved recently to accept finer material (minus 2 mm plus 0.5 mm).

Currently the operation produces about 40% of its ore feed as fines, about one-half of which are sintered in the 250,000 t/yr sintering plant at Bell Bay, Tasmania. This sinter accounts for about 65% of the feed to the company's ferromanganese smelter at the same location. This smelter was upgraded in 1986-87, and by increasing the total rating from 59 KVA to 92 KVA, along with facility modernization, capacity was increased from 135,000 t/yr to about 200,000 t/yr (effective HCFeMn) (*16*).

In recent years, sinter has been increasingly exported to Japan as prime material for use in the direct addition process as discussed in the technology section.

BRAZIL

The most recent significant development in Brazil was the opening of the Azul Mine in the Carajas Mineral Province. This was made possible by development of the Carajas iron mining and processing facilities, which was facilitated by completion of a 900 km railway from this region to a port at Sao Luis, Maranhao State.

Serra do Navio Mine

The Serra do Navio Mine, owned by Industria e Comercio Minerios (ICOMI), is still the largest producer in Brazil; however, its economic resources are limited.

Capacity of the operation is about 1 million t/yr; however, recent production has been somewhat less. Since the previous study, the pelletizing plant has been dismantled and converted to a 50,000 t/yr sintering plant, whose capacity, however, can be increased to 100,000 t/yr.

Remaining resources are estimated to last possibly 5 to 7 years. This estimate would put resources at approximately 14 to 15 million tons of in situ material that can be upgraded to marketable concentrates. The original high-grade material is nearly depleted.

Azul Mine/Buritirama

The Azul Mine in the Carajas mineral province is owned by the Federal Government company, Cia. Vale Rio Doce (CVRD). The deposit was discovered in 1971 and began production in 1985.

Manganese ore occurs over a length of 4300 m, in widths of 50 m to 300 m. Ore is composed mainly of cryptomelane and pyrolusite minerals with gibbsite and kaolinite as the main gangue. The deposit contains an estimated 65 million tons of ore (in situ) at a grade of 42% Mn.

Mining is by open pit with 4 m high benches, and the ore is hauled by 10 t trucks about 1 km to the mill. Milling consists of crushing, wet screening, and spiral classifying to produce three products: lump (minus 3 inch plus 5 mesh), medium coarse (minus 3/8 inch plus 5 mesh), and sinter feed (minus 1/4 inch plus 100 mesh). At present there is little market for the sinter feed. Total manganese recovery in three products is about 50%. Recovery problems lie mainly in softness of the ore, which produces a high percentage of fines during beneficiation.

Concentrate is hauled 30 km to the iron ore loading facility, where it is stockpiled until a trainload is accumulated.

The company is currently contemplating a sintering operation at Sao Luis to utilize the fines.

The Buritirama deposit is located about 50 km north of the Azul Mine. Little data are available concerning this deposit, and thus it is not included in the evaluations. The deposit was recently purchased from BHP Utah by Prometal Productos Metalurgicos SA. Resources have been stated to as much as 18 million tons (*5*), but with somewhat uncertain preciseness.

Mato Grosso do Sul

The Corumba area, in this State, has changed character very little in recent years. Two small mines are still operating; these are the Urucum Mine owned by Urucum Mineracao, a CVRD subsidiary, and the Santana Mine owned by Cia. Paulista de Ferro-Ligas. The area also contains a large quantity of iron ore resources.

Three manganese beds with thickness ranging up to 6 m occur in this area. The manganese oxide beds are almost all intercalated between clastic beds in an iron formation. Average analysis of the manganese oxide lenses in the Urucum is about 46% manganese. Owing to limited exploration, resource estimates are somewhat subjective. They have been variously estimated depending on the criteria used. One estimate (*12*) states 72 and 5 million tons, respectively, for the Urucum and Santana mines; another (*13*, p. 105) states 44 and 4 million tons, respectively; and the Anuario Mineral Brasilerio 1987 (*6*, p. 253) states 71 and 67 million tons indicated and inferred, respectively, for the Corumba District. Estimates would probably be better defined as a future potential resource, or as dependent on development of iron resources in the area.

Concentrates are shipped from the Urucum Mine both by barge and rail. Barge shipments are seasonal and are destined for export via the Paraguay River to Montevideo, Uruguay. Rail shipments generally go to smelters in the Sao Paulo area. The Santana Mine primarily produces concentrates as feed for a company smelter at Corumba.

Total production has generally been less than 100,000 t/yr for each mine. Mining is by room and pillar on the relatively flat lying lower bed. An advantage is that enclosing rocks are quite competent, and the in situ ore is

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PUBLICATIONS INVENTORY

Program Descriptions:

____	IC 8654	The Bureau of Mines Minerals Availability System and Resource Classification Manual, 1974.
____	IC 8815	MILS: The Mineral Industry Location System of the Federal Bureau of Mines, 1980.
____	IC 8820	Supply Analysis Model (SAM): A Minerals Availability System Methodology, 1980.
____	IC 8887	The Bureau of Mines Minerals Availability System: An Update of IC 8654, 1982.
____	Bulletin 692	An Appraisal of Minerals Availability for 34 Commodities, 1987.

Availability Information Circulars (IC)

____	IC 8809	Copper Availability - Domestic, A Minerals Availability System Appraisal, 1979.
____	IC 8848	Cobalt Availability - Domestic, A Minerals Availability System Appraisal, 1981.
____	IC 8861	Alumina Availability - Domestic, A Minerals Availability System Appraisal, 1981.
____	IC 8889	Manganese Availability - Domestic, A Minerals Availability System Appraisal, 1982.
____	IC 8895	Chromium Availability - Domestic, A Minerals Availability System Appraisal, 1982.
____	IC 8897	Platinum Availability - Market Economy Countries, A Minerals Availability System Appraisal, 1982.
____	IC 8917	Aluminum Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1983.
____	IC 8930	Copper Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1983.
____	IC 8937	Phosphate Rock Availability - Domestic, A Minerals Availability Program Appraisal, 1983.
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____	IC 8977	Chromium Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1984.
____	IC 8978	Manganese Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 8988	Nickel Availability - Domestic, A Minerals Availability Program Appraisal, 1985.
____	IC 8989	Phosphate Rock Availability - World, A Minerals Availability Program Appraisal, 1985.
____	IC 8995	Nickel Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 9012	Cobalt Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 9025	Tungsten Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 9026	Primary Lead and Zinc Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 9036	Asbestos Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1985.
____	IC 9038	Mercury Availability - Market Economy Countries, A Minerals Availability Appraisal, 1985.
____	IC 9044	Molybdenum Availability - Market Economy Countries, A Minerals Availability Appraisal, 1985.
____	IC 9060	Fluorspar Availability - Market Economy Countries, A Minerals Availability Appraisal, 1985.
____	IC 9061	Titanium Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9070	Gold Availability - World, A Minerals Availability Appraisal, 1986.
____	IC 9084	Potash Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9085	Columbium Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9086	Tin Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9090	Primary Silver Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9098	Antimony Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9100	Beryllium Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9102	Lithium Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9115	Barite Availability - Market Economy Countries, A Minerals Availability Appraisal, 1986.
____	IC 9106	Elemental Sulfur and Pyrite Concentrate Availability, 1987 - Market Economy Countries, A Minerals Availability Appraisal, 1987.
____	IC 9111	Availability of Rare Earth, Yttrium and Related Thorium Oxides--Market Economy Countries, A Minerals Availability Minerals Availability Program Appraisal, 1987.
____	IC 9112	Magnesium Availability - Market Economy Countries, A Minerals Availability Appraisal, 1987.
____	IC 9122	Natural Flake Graphite Availability - A Minerals Availability Appraisal, 1987.
____	IC 9128	Iron Ore Availability - Market Economy Countries, A Minerals Availability Program Appraisal, 1987.
____	IC 9187	Phosphate Availability and Supply: A Minerals Availability Appraisal, 1988.
____	IC 9276	Availability of Primary Nickel in Market Economy Countries, A Minerals Availability Appraisal, 1991.
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____	IC 9310	The Availability of Primary Copper in Market Economy Countries, A Minerals Availability Appraisal, 1992.

relatively uniform and high grade, requiring only crushing. One disadvantage is that it contains a high alkali content that must be either blended or smelted by a duplex process. Another is location, with transportation distances of 2700 km by barge, or 1700 km by limited-capacity rail.

Other Areas

Other areas in Bahia, Goias, and Minas Gerais States have contributed about 650,000 t/yr production in recent years; however, this is from a relatively large number of small operations, and resources of individual deposits are quite small. Estimates indicate Bahia has resources of about 2.5 million tons in 14 deposits, Goias 1.2 million tons in 10 deposits, and Minas Gerais 13 million tons in 26 deposits (*6*, p. 253).

Production is mainly in the form of lower grade (less than 35% Mn) metallurgical ore for ferroalloy plants, ferruginous manganese ore for iron blast furnaces, and carbonate ore, some of which is calcined for ferroalloy plants, and some of which is used for electrolytic manganese dioxide (EMD) production.

The main production is in the State of Minas Gerais where mines are relatively close to steel plants at Belo Horizonte and five Cia. Paulista de Ferro-Ligas manganese ferroalloy plants.

These deposits are not expected to contribute significantly to long-term supply. Currently, many of the mines are operating in somewhat of a maintenance mode, especially with the decrease in demand for ferruginous ore.

GABON

Manganese ore in Gabon occurs in the uplands in the southeast part of the country, in a relatively remote area near Franceville. The area is about 600 m in elevation and is mainly covered with savannah-type vegetation. Manganese enriched areas consist of five plateaus elevated about 150 m above the surrounding area; these are Bangombe, Okuoma, Massengo, Bafola, and Yeye.

Mining is currently on the Bangombe Plateau, which is probably the richest of the deposits, although, similar type ore occurs on the Okouma Plateau as well. The operation is owned and operated by Compagnie Miniere de l'Ogooue S.A. (Comilog). Current mine capacity is about 2.5 million tons per year.

Total in situ resources of the five plateaus have been stated as 400 million tons. There is no doubt about the existence of these resources; however, most of these would require additional exploration and development. Resources assumed for this study are about 100 million tons of in situ ore on the Bangombe Plateau. In addition to this plateau, the Okouma Plateau may contain another 50 million tons of similar grade resources. At current capacity the Bangombe resource should last about 20 years.

Mining at the Moanda Mine is probably the simplest of all manganese mining operations. The ore is flat lying, and both ore and overburden are soft enough to be excavated by draglines or scrapers. Two 12 m^3 draglines work on 20 m panels about 600 to 900 m long. The ore horizon is about 5 to 6 m thick and is generally covered by a similar thickness of overburden. Average haul distance is about 6 km on a level grade.

Beneficiation consists of sizing and washing, with a heavy media circuit mainly for battery grade ore. There are three metallurgical products produced: minus 80 mm plus 6 mm (50.7% Mn and about 90% of the product), minus 6 mm plus 2 mm (49.0% Mn and about 7% of the product), and a small amount (about 1% of the product) of high grade (52.5% Mn) from the heavy media circuit (16). Production of battery grade ore amounts to perhaps 100,000 t/yr.

Recently, ore to concentrate ratio has been about 1:7, that is about 5.1 tons of ore has been used to produce 3 tons of product (*18*). Manganese recovery is about 62.5%; losses occur mainly in fines (minus 2 mm) because of the soft nature of the ore.

Concentrate is transported partially by 76 km ropeway and 485 km railroad to Pointe Noire, Congo. However, rail and port facilities are operational for transportation over the 560 km Trans-Gabon railroad to ship loading facilities at the port of Owendo, near Libreville. Recent information has indicated that ore shipments will be split 50-50 between the two routes in the future.

As stated previously, mining and beneficiation at Moanda is probably the simplest of all manganese mines, although infrastructure to support the facilities is probably the most complex. A total of more than 3,800 personnel were employed in the operation, and are classified as shown below (*18*):

Classification	Employees
Central administration	276
Mine	1,022
Ropeway	859
Railroad	1,443
Port	233
Total	3,833

To support this labor force, the company had over 2,000 lodging units, four hospitals, several primary and secondary schools, and various clubs and sport facilities. Transportation and infrastructure amounted to about 90% of the production cost delivered to Pointe Noire in 1985.

GHANA

Manganese ore deposits of the Nsuta Mine are located about 62 km from the port of Takoradi and are owned by Ghana National Manganese Corporation. Deposits occur on five hills and can be traced almost continuously for about 4 km. The hills are elevated 60 m to 90 m above the surrounding area.

Ore bodies, that have been mined in the past, are sedimentary lenses rich in battery-grade manganese oxides from laterizations and oxide enrichment of gondites. The principal manganese mineral in the remaining resources is rhodochrosite ($MnCO_3$).

The mine has operated for over 60 years and has been a major supplier of battery-grade oxide ore, but reserves of this type of ore are nearly gone. About 60% of the production in recent years has been carbonate ore.

A nodulizing plant was completed in 1982 for the purpose of converting manganese carbonate mineral to an oxide, which would raise the grade from 31% Mn to 44% Mn. This plant, however has been sitting idle, and to be placed into operation, it would probably have to be nearly completely rebuilt.

INDIA

Manganese deposits in India are quite numerous although the material that may be applicable for use in making ferromanganese is limited; for this study it is assumed that only ore with plus 35% Mn would be applicable.

Available data indicates occurrences in some 24 districts located in 11 States, containing about 135 million tons of material in all grade categories (*3*). Of this, about 30 million tons contain more than 35% Mn, of which about 23 million tons and 5 million tons are contained, respectively, in the Maharashtra - Madhya Pradesh manganese area (Bandara, Nagpur, and Balaghat districts) and the Keonjhar area in Orissa State.

The main production of higher grade ore is from these areas. The Maharashtra - Madhya Pradesh area has about 8 to 10 mines, mainly underground, and the Keonjhar area may contain as many as 200 individual open pit operations.

Mining and beneficiation of Indian manganese ores are mainly by hand methods. Production in India has been declining somewhat in recent years and could be expected to decline further with the advent of new methods of steelmaking, which are limiting the need for low grade manganese ore.

A major problem in India is obtaining quality ore for a good smelting blend; quality ore is mainly from mines in Madhya Pradesh. To the south, in Mahrashtra, much of the ore has a high phosphorus content, and the ore of Keonjhar has a relatively low manganese and high iron content.

MEXICO

The only significant manganese resource in Mexico is at the Molango Mine located in Hidalgo State about 140 km southwest of Tampico. It is owned by Compania Minera Autlan S.A. de C.V.

Ore occurs at the base of the Chipoco Formation and has been identified over an area of 20 by 50 km; however, manganese mineralization does not necessarily occur throughout. Resources have been variously reported to be as much as 200 million tons to a grade of 10% Mn. For this study, in situ quantity is assumed at 34 million tons at a grade of 28% Mn in the form of manganese carbonate ($MnCO_3$).

Mine production began as an open pit operation in 1969, and in 1978 an underground room and pillar operation began. The open pit has only a few years left and produces about 150,000 t/yr of a total 800,000 t/yr ore production.

Processing is mainly by nodulizing, where $MnCO_3$ is converted to an oxide by driving off CO_2 in a kiln, resulting in a nodule grade of about 39% Mn. Other concentrating methods include gravity separation using jigs and a heavy media process; these are used when ore is diluted by silica during mining.

Nodule capacity is about 525,000 t/yr, which is hauled about 240 km to Tamos or Tampico for smelting or export, respectively. The smelter at Tamos has a capacity of about 100,000 t/yr FeMn, 60,000 t/yr SiMn, and 40,000 t/yr MCFeMn. The company also owns a smaller smelter at Tezuitlan and jointly with Hornos Electricos de Venezuela. Nodules are used by a number of smelters, because of their good smelting characteristic and very low phosphorus content.

REPUBLIC OF SOUTH AFRICA

The Republic of South Africa is still predominant in MEC manganese resources and production. Of the MEC demonstrated resources evaluated in this study, the country holds nearly 60%, in terms of in situ ore and contained manganese. It also has about 40% of the MEC ore production capacity and more than 15% of its smelter capacity.

Virtually all manganese ore in South Africa occurs in the Kalahari field, which is located in the northern part of the Cape province. The Postmasburg area, south of the Kalahari field, was mined on a relatively small scale for a number of years; however, ore was low grade and used mainly for its lime content. These mines are now considered to be permanently shut down. The Middleplaats Mine, developed in 1979, was shut down in 1983.

Because of the large areal extent of the ore horizons and the vastness of the quantities, manganese resources in South Africa are difficult to present with any degree of preciseness. The Kalahari field extends for about 40 km north-south and contains consistent manganese strata throughout its entire length. Total resources have been estimated at about 13.6 billion tons to a grade of plus 20% Mn (*20*). In this study, allowing for production since 1980, and shutdown of the Postmasburg and Middleplaats Mines, the total demonstrated resources are assumed at 710 million tons. These resources are within orebodies being mined, and may be understated, when considering total resources of similar character available through additional development.

Operations now include four major mines and a few intermittent operations. Major mines are operated by two companies: Associated Manganese Mines of South Africa, Ltd. (AMMOSAL), which operates Gloria and Nchwaning Mines and the smaller Black Rock and Belgravia Mines in the Black Rock area at the northern extremity of the field; and SAMANCOR, Ltd., which operates the Wessels Mine in the Black Rock area and Mamatwan Mine at the southern end of the field.

There are basically two stratigraphies that are currently being mined: high grade, relatively thin manganese beds in the north (Black Rock area) and massive strata in the south. In the north, mining is by underground methods, mainly on a 3 to 5 m bed which is lowest of three manganese bearing strata in the area. A middle bed (0.5 m to 2 m thick) is considered too thin to mine; however, an upper bed is mined in a few places on a smaller scale. In the south, the open pit Mamatwan Mine is developed on a 20 m bed in a massive 45 to 50 m thick unit, overlain by a similar thickness of overburden.

High grade (44% to 50% Mn) manganese ore in the north is actually restricted to the extreme north end of the field in the Nchwaning and Wessels Mines. In the Gloria Mine, immediately to the south, the grade drops to about 40% Mn; the grade in the Mamatwan Mine averages about 38% Mn.

Geologic structure in the field consists mainly of a gently folded syncline with dips ranging from 5° to 20° to the west. Folds and faults occur in the northern mines, but these do not seriously affect mining. Mining horizons are relatively continuous for long distances, although there are some stratigraphic and mineralogical variations that affect exploitation.

Black Rock Area

The area was named for the small "black rock" manganese ore outcrop, which contributed the first ore from the Kalahari field and initiated its discovery.

Gloria Mine

The Gloria Mine is accessed by a 170 m deep, circular, two-compartment shaft and a 1,079 m decline to a depth of 180 m. The decline is the main entry way, is used for transporting both personnel and materials, and contains a conveyor for transporting ore. The shaft has two hoists, one equipped with ore skips and another with a single deck man cage; the shafts are used mainly as standby.

Mining is by room-and-pillar with an initial mine recovery of 70%. This can be increased later by removing pillars. Ore is crushed underground and transported to the surface by a conveyor located in the decline. Milling consists of final crushing, washing, and screening to sizes required by customers. Capacity is estimated at about 600,000 t/yr.

Nchwaning Mine

The Nchwaning Mine is similar to the Gloria Mine in mining and milling methods. The differences are that it is deeper, 455 m, has a larger capacity (estimated at 1 million t/yr), and utilizes some hand sorting.

The mine, as with Gloria, is accessed by a vertical shaft and decline; here, however, ore is hoisted through the shaft, and the decline is used for transport of personnel and materials. The surface plant has a sorting section of five belts for hand picking waste from generally minus 125 mm plus 50 mm material.

Belgravia and Black Rock Mines

These are small mines compared to the Gloria and Nchwaning. Access to the Belgravia is by two vertical shafts and an incline. At the Black Rock, mining started from the outcrop and continues through use of several inclines.

Wessels Mine

The Wessels Mine is similar to the Gloria and Nchwaning Mines and lies immediately north of the Nchwaning; it basically produces from the same strata.

The mine is accessed by a 393 m vertical, two-compartment shaft (production level at 365 m) and a 1,800 m decline that contains a cable conveyor system for transporting ore to the surface. The shaft is principally used for the transport of personnel and materials.

From working faces, ore is hauled to primary crushing stations where it is reduced to minus 125 mm, and then to secondary crushers where it is reduced to a final size of 63 mm, before it is transferred to the cable belt for transport to the surface.

Mining is on two ore bodies, "north" and "south," and the manganese bed is 3 to 5 m thick. Because of variations in ore thickness and folds, the size of the equipment is somewhat limited. Mine capacity is assumed to be about 1.2 million t/yr; capacity of the cable belt system is about 1,000 t/hr.

Mamatwan Mine

The Mamatwan Mine is located at the southern extremity of the Kalahari Field. Ore varies in thickness from the subcrop to about 50 m; however, only about a 20 m thickness is mined.

The total ore zone consists of about a 20 m upper member containing 30% Mn, a middle 20 m member with 38% Mn, and a lower 6 m thick, 30% Mn member. The middle member is mined after removal and stockpiling of the upper member; the lower member is left in place.

Overburden (about 45 m) consists of hard limestone, ironstone, and sand; the sand (about 7 m) is removed by a bucket wheel excavator. Hard overburden is mined in three benches; about 70% of it is used as backfill in mined out areas.

In 1981 an in-pit crusher and 2.2 km conveyor system were installed to reduce dependence on truck haulage. Conveyor capacity was designed at about twice the crushing capacity for potential future expansion that would only require installation of another crushing system. Current maximum capacity is estimated to be in the order of 1.2 million t/yr product.

At the secondary crushing and screening plant, ore is crushed to a minus 75 mm and wet-screened into plus 25 mm, minus 25 mm plus 6 mm, and minus 6 mm size.

In 1988 a 500,000 t/yr sinter plant was constructed to sinter the fines (minus 6 mm) generated by crushing and handling. The ore is quite hard and produces about 30% of the ore as fines. Currently this plant upgrades the ore from about 38% Mn to 44% Mn. The operation was described in detail in a recent report (*11*).

Experimentation in sintering began in the early 1970's, and in 1978 large scale testing began, with subsequent use of the material as feed to ferroalloy smelters. This culminated in the plant being constructed and going on stream in July 1988.

A heavy media plant is planned for the operation, which would increase the sinter feed grade and resulting sinter grade. In addition, the company is contemplating increasing sintering plant capacity.

South Africa currently has three ferromanganese smelting plants (see Appendix A). Total manganese ferroalloy capacity in South Africa is in the order of 450,000 t/yr HCFeMn and 300,000 t/yr SiMn.

AVAILABILITY UPDATE

This study analyzed the potential production from 14 MEC operations, some of which are a combination of small mines contributing to 1 operation, such as those in India. U.S. deposits are not included, since their production costs are in the order of eight times the cost of the highest cost non-U.S. mines. Total in situ demonstrated resources analyzed amount to a little over 1.1 billion tons containing about 475 million tons of manganese, which translates to about 335 million tons of contained manganese in 800 million tons of concentrates.

Production costs were determined generally through analysis of the engineering data, personnel requirements, energy usage, infrastructure, etc. Relationships between mining, beneficiation and transportation costs are shown in figure 4.

Because of the remoteness of mining operations, transporting concentrates to market and the cost of support facilities, such as housing, schools, medical care, etc., will continue to be a major part of production costs.

Availability of manganese from each deposit is presented in this study as a function of total cost associated with development, mining, concentration, and transportation to assumed markets. Evaluations are based on utilization of the entire resource of each deposit. Deposit production cost data are aggregated and are illustrated in the form of a curve shown in figure 5. Costs are shown in terms of 1989 dollars per long ton unit (ltu) or 22.4 lbs of contained manganese.

As is well known, MEC availability of manganese is restricted to a very few deposits, regardless of production cost. Weighted average grade of the demonstrated resources is nearly 40% Mn, and, after concentration, weighted average product grade is about 46% Mn. Thus, concentration needs to increase grade overall by only about 6%. Nearly all of this is done by simple sizing and washing. Under these circumstances, it is difficult to contemplate the existence of any other resources that could compete economically with the current producing deposits, even through the exploitation of the identified resources, which would require additional exploration and development.

Additionally, rarely can smelting be done efficiently using only a single concentrate. Most smelters, in order to obtain optimum efficiency in producing manganese ferroalloys, must utilize several concentrates to build a furnace charge with appropriate chemical and physical properties. This somewhat precludes production cost as a determining factor in projecting production from a particular mine.

Thus, production costs of ore and concentrate, depicted in figure 5, are estimates of base costs, below which it would probably be difficult to maintain production. As illustrated, production costs range from about $1.05/ltu to $1.86/ltu.

There are no other manganese resources in the MEC's that could be produced at anywhere near the cost of these current producers. Estimated production costs of U.S. deposits, as an example, would range from about $9/ltu to $17/ltu.

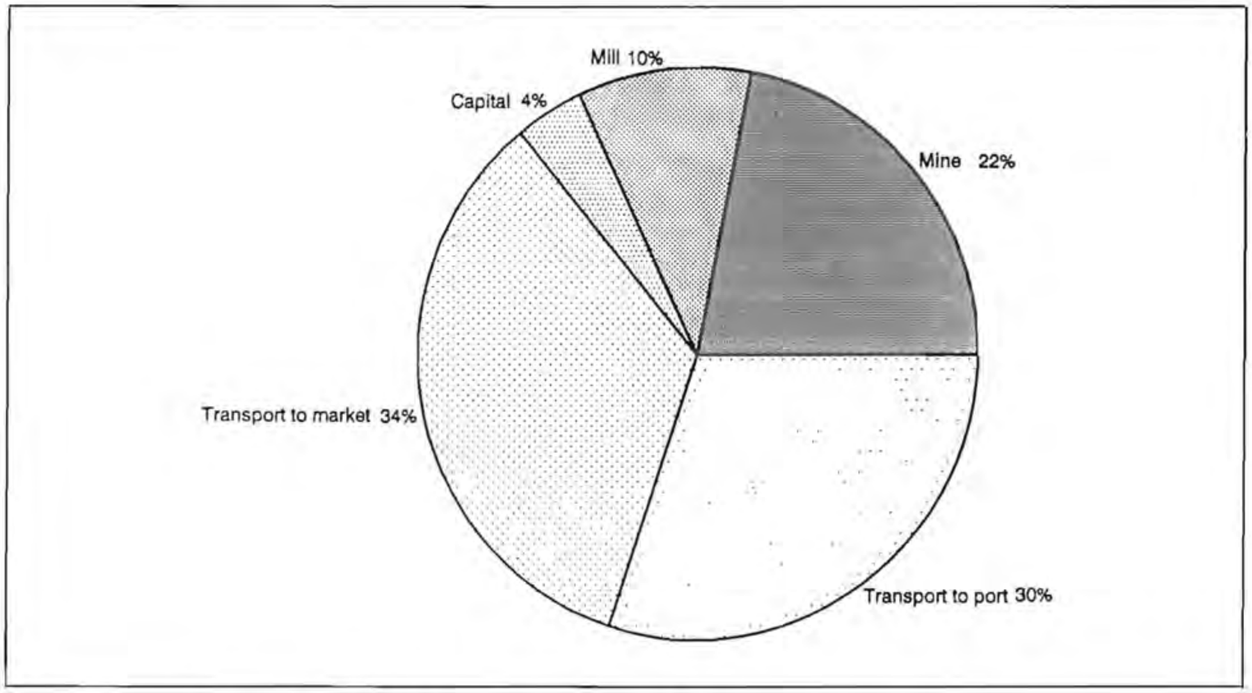

Figure 4.—Relationship of cost elements through manganese concentrate production.

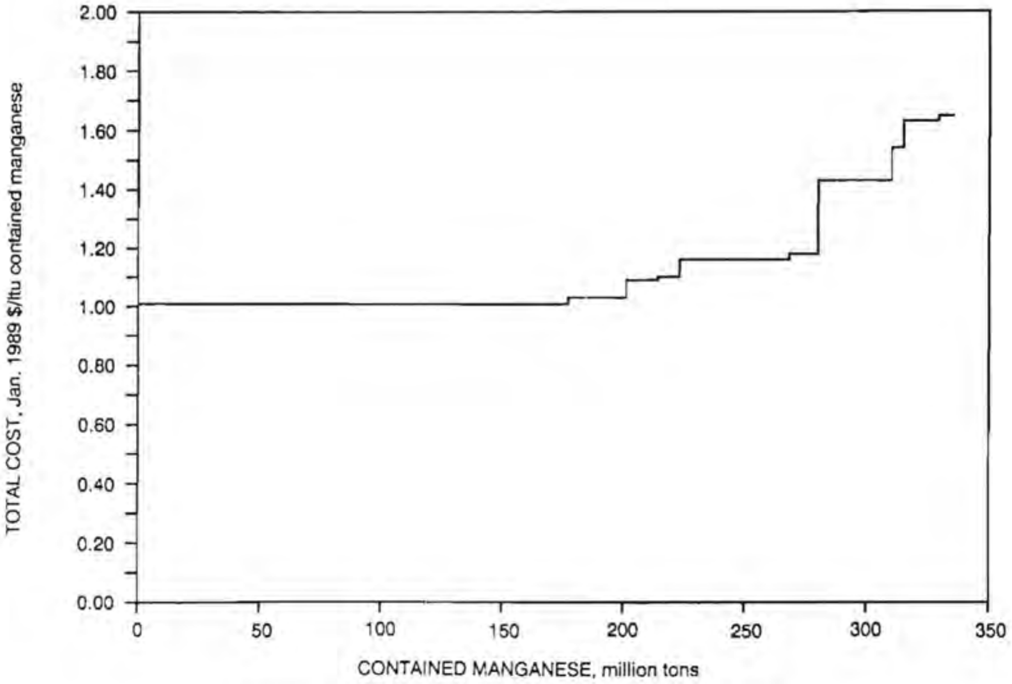

Figure 5.—MEC manganese availability, 0% DCFROR.

CONSUMPTION/DEMAND

Demand and consumption of metallurgical manganese is nearly totally dependent on steel production. Probably less than 5% is used for alloying in other metals, such as aluminum and copper-based alloys.

World steel production, by regions for the period of 1976 to 1987, is shown in table 5. In this period world production of steel increased by about 8.4%. Major MEC industrial countries showed decreases in steel production, and by far the greatest production decrease was in the United States. The largest increases were in the developing Asian countries, which could indicate areas of future manganese demand increase.

The totals of table 5 are combined with manganese data in table 6 to illustrate trends of manganese usage. As shown, statistics during this period indicate an overall decrease in usage of manganese as ferroalloy per ton of raw steel of about 13% in the MEC's and an increase of 11% in the CPEC's. Data, with respect to the two economic entities (MEC's and CPEC's), however, is somewhat skewed, in that CPEC's currently import in the order of 1 to 1.5 million tons per year of concentrates from the MEC's.

Table 5.—World raw steel production by region, 1976-87 (thousand tons, unless otherwise noted)

Region and country	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	% change[1] 1976-87
Market economy:													
Africa:													
South Africa, Republic of	7,154	7,375	7,900	8,866	9,066	9,002	8,269	7,189	8,286	8,580	8,798	8,698	22
Other	2,704	2,476	4,097	5,108	4,980	3,937	3,812	4,462	3,957	5,967	5,994	5,986	121
Total	9,858	9,851	11,997	13,974	14,046	12,939	12,081	11,651	12,243	14,547	14,792	14,684	49
Asia:													
Japan	107,377	102,384	102,084	111,726	102,303	101,655	99,565	97,159	105,565	105,258	98,256	98,493	(8)
Australia	7,772	7,312	7,587	8,123	7,593	7,634	6,378	5,656	6,302	6,577	6,710	6,041	(22)
Other	14,250	17,775	20,315	23,038	21,932	26,931	29,203	30,317	32,113	33,970	36,406	39,592	178
Total	129,399	127,471	129,986	142,887	131,828	136,220	135,146	133,132	143,980	145,805	141,372	144,126	11
Europe	162,775	154,696	162,771	172,921	171,176	158,012	143,100	142,475	156,708	157,150	147,856	149,314	(8)
North America:													
United States	116,096	113,677	124,288	123,662	101,435	109,591	67,642	76,746	83,923	80,051	74,017	80,860	(30)
Other	18,596	19,242	21,683	23,203	23,054	22,532	19,000	20,027	22,479	22,049	21,604	22,591	21
Total	134,692	132,919	145,971	146,865	124,489	132,123	86,642	96,773	106,402	102,100	95,621	103,451	(23)
South America:													
Brazil	9,167	11,162	12,105	13,891	15,336	13,228	12,998	14,658	18,383	20,452	21,230	22,226	142
Other	4,560	4,812	5,017	6,153	5,825	5,795	6,434	6,967	7,172	7,979	8,558	8,937	96
Total	13,727	15,974	17,122	20,044	21,161	19,023	19,432	21,625	25,555	28,431	29,788	31,163	127
Total MEC	450,451	440,911	467,847	496,691	462,700	458,317	396,401	405,656	444,888	448,033	429,429	442,738	(2)
Centrally planned:													
China	20,499	23,736	31,774	34,424	37,113	35,593	37,153	39,945	43,355	46,711	52,052	55,962	173
U.S.S.R.	144,796	146,649	151,442	149,069	147,911	148,415	147,135	152,483	154,207	154,637	160,518	161,991	12
Europe	53,900	57,542	59,637	60,364	61,513	57,597	56,268	57,508	59,989	59,387	60,718	61,513	14
Other	3,656	3,859	3,967	4,182	6,865	6,584	6,850	7,198	7,668	7,762	7,779	7,739	112
Total CPEC	222,851	231,786	246,820	248,039	253,402	248,189	247,406	257,134	265,219	268,497	281,067	287,205	29
Grand total	673,302	672,697	714,667	744,730	716,102	706,506	643,807	662,790	710,107	716,530	710,496	729,943	8

[1] Parentheses indicate a decline in production.

Source: Bureau of Mines Yearbook, various years, iron and steel chapter (*24*).

Table 6.—Derived unit manganese concentrate and metal use in steel[1], 1976-87
(thousand tons, unless otherwise noted)

Commodity	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	% change[2] 1976-87
Market economy:													
Raw steel	450,451	440,911	467,847	496,691	462,700	458,317	396,401	405,656	444,888	448,033	429,429	442,738	(2)
Manganese concentrates	14,968	12,985	12,171	14,406	14,889	12,675	11,635	10,182	11,782	12,677	12,702	11,568	(23)
Kg Mn concentrates/ton raw steel	33.23	29.45	26.01	29.00	32.18	27.66	29.35	25.10	26.48	28.29	29.58	26.13	(21)
Ferromanganese	3,415	3,055	3,112	3,718	3,398	3,221	2,965	2,413	2,828	2,790	2,619	2,581	(24)
Silicomanganese	928	872	954	1,089	1,149	1,055	1,063	1,040	1,271	1,200	1,185	1,237	33
Contained Mn in ferroalloy[3]	3,267	2,950	3,047	3,608	3,397	3,198	3,004	2,558	3,032	2,956	2,813	2,817	(14)
Kg Mn/ton raw steel	7.25	6.69	6.51	7.26	7.34	6.98	7.58	6.31	6.82	6.60	6.55	6.36	(12)
Centrally planned economy:													
Raw steel	222,851	231,786	246,820	248,039	253,402	248,189	247,406	257,134	256,219	268,497	281,067	287,205	29
Manganese concentrates	9,807	9,879	10,708	11,963	11,479	10,922	11,602	11,656	11,842	11,650	11,107	11,108	13
Kg Mn concentrates/ton raw steel	44.01	42.62	43.38	48.23	45.30	44.01	46.89	45.33	46.22	43.39	39.52	38.68	(12)
Ferromanganese	1,792	1,935	2,034	2,234	2,611	2,108	1,933	2,010	2,107	2,181	2,328	2,380	33
Silicomanganese	26	30	30	30	63	65	68	208	221	229	240	239	819
Contained Mn in ferroalloy[4]	1,343	1,451	1,525	1,673	1,973	1,602	1,475	1,623	1,703	1,763	1,879	1,917	43
Kg Mn/ton raw steel	6.03	6.26	6.18	6.74	7.79	6.46	5.96	6.31	6.65	6.57	6.68	6.67	11

[1] Country specific production data for raw steel is found in table 5, manganese concentrates in table 1, and ferromanganese and silicomanganese in table 2.

[2] Parentheses indicate a decrease.

[3] Based on assumed Mn content of 78% in ferromanganese and 65% in silicomanganese.

[4] Based on assumed Mn content of 74% in ferromanganese and 65% in silicomanganese.

The U.S.S.R. is the principal figure in the CPEC manganese industry, since it produces 50% of the steel, about 60% of the manganese ferroalloys, and nearly 85% of the manganese ore. Its imports of manganese concentrates and ferroalloys from the MEC's will probably increase in the future, since its higher quality manganese resources are nearly depleted (*19*). China will undoubtedly also be a major importer as its steel industry expands.

U.S. manganese consumption statistics, for 1976 to 1987, are shown in table 7. As portrayed, consumption has declined from 6.44 to 4.70 kg/t of raw steel, a 28% decrease. If manganese use, per ton of steel, was the same as in 1976, the 1987 consumption would have been increased by about 147,000 tons of manganese content or a little more than 212,000 tons HCFeMn equivalent.

Worldwide, based on present levels of manganese and steel production, on the total world consumption of manganese per unit of steel, and on the assumed manganese content of the ferroalloys, consumption has decreased by about 0.4 kg Mn/t of raw steel. Annually, this would amount to about 300,000 tons of contained manganese, or about 500,000 tons of ferroalloys, which would consume over 1 million tons of concentrate.

A production of 730 million tons of steel in 1987 apparently required a production of 4,726,000 tons of contained manganese in ferroalloys. However, possible discrepancies in CPEC Mn data reporting could boost total manganese consumption by some 300,000 tons. If so, it appears reasonable to use a production (consumption) figure of 5 million tons of contained manganese. This would roughly translate to about 5 million tons of FeMn and 2 million tons of SiMn.

Table 7.—U.S. manganese consumption and derived Mn content of U.S. produced steel, 1976-87 (tons, unless otherwise indicated)

Manganese consumption factor	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	% change[1] 1976-87
Manganese consumption by end use:													
High carbon FeMn	685,464	678,537	754,183	745,665	604,233	617,909	328,939	332,827	363,599	344,836	264,233	292,193	(57)
Medium and low carbon FeMn	127,911	125,337	139,777	140,005	111,459	126,666	69,413	71,967	82,793	77,411	76,664	79,114	(38)
Silicomanganese	140,157	134,017	149,027	155,914	141,326	141,257	95,820	75,637	93,044	95,034	93,212	103,892	(26)
Metal	25,510	24,465	25,608	25,502	22,758	21,568	15,547	16,554	25,300	22,226	21,895	23,191	(9)
Total manganese (contained MN)[2]	748,027	735,573	816,416	814,412	670,161	691,775	387,337	380,288	432,812	412,224	348,040	379,792	(49)
Raw steel production (10^3 tons)	116,096	113,677	124,288	123,662	101,435	109,591	67,642	76,746	83,923	80,051	74,017	80,860	(30)
Kg Mn/ton raw steel	6.44	6.47	6.57	6.59	6.61	6.31	5.73	4.96	5.16	5.15	4.70	4.70	(27)

[1] Parentheses indicate a decrease.

[2] Assuming Mn content as follows: HCFeMn-77%, MC and LCFeMn-81%, SiMn-65%.

Source: Mn consumption and raw steel production from manganese and iron and steel chapters of the Bureau of Mines Yearbook, respectively, various years.

Steel production projections have been variously reported to increase by 0.7% to over 2% per year, from 1986 to 1995 (*4*). Some areas, such as the developing countries, and some CPEC's, particularly China, are projected to have relatively large increases in production, up to possibly 6% per year. In contrast, the steel production of the developed MEC's (Europe, Japan, and the United States) are expected to remain relatively static. Even in the U.S.S.R., rather than increase production, some experts envision the production and utilization of steel as becoming more efficient, thereby, reducing the need to increase production.

On a worldwide basis, table 8 portrays the years 1995 and 2000 projection scenarios of steel production, manganese ore, FeMn, and SiMn demand, assuming the 1987 interrelationships between steel and manganese ferroalloys, and concentrates.

Table 8.—Projected 1995 and 2000 world steel, manganese concentrate, and Mn ferroalloy production for various growth rates[1] (million tons, unless otherwise noted)

% Growth rate	Steel		Mn concentrate		FeMn		SiMn	
	1995	2000	1995	2000	1995	2000	1995	2000
0.7	772	799	24.0	24.8	5.2	5.4	2.1	2.2
1.2	803	853	25.0	26.5	5.5	5.8	2.2	2.3
1.6	830	899	25.8	27.9	5.6	6.1	2.3	2.5
2.0	857	947	26.6	29.4	5.8	6.4	2.3	2.6

[1] Projected production is based on 1987 production figures, except SiMn which has been adjusted to reflect underreporting of production in the CPEC's. Assumes Mn to raw steel ratio remains at 1987 ratio over length of projection.

Projections based on the formula:

$$FP = A\hat{}\,(r*T),$$

where FP = future production in given year (1995, 2000),

A = base year production (1987),

r = growth rate,

T = number of years.

SUPPLY

As stated previously, manganese supply is available from only a few select areas in the world; there are many areas of minor manganese occurrences throughout the world, but these do not approach the quantity or quality of major producing deposits. As a result, economical exploitation of manganese will, for many years, be limited almost entirely to currently producing deposits.

In view of the low quality of future ore availability in the CPEC's, these countries will probably increasingly rely on materials from MEC deposits to meet their needs. In general the quality of ores from the rest of the CPEC's (outside the U.S.S.R.) are low grade and are considered somewhat insignificant. Little is known about manganese production potential in China, although limited information available suggests that their ores are quite low grade (about 20% Mn) and deposits are at considerable distances from markets.

With the U.S.S.R. accounting for 85% of CPEC ore production, its position is almost singularly paramount in assessing their future manganese supply situation. In this respect, and even in recent years of increasing steel production, U.S.S.R. manganese ore production has declined about 2% per year since 1984.

This suggests an approximate annual production level of 7.3 million tons in the year 2000; however, it is felt that 5 million tons would probably be a more realistic production estimate, since reserves of high grade ore are declining. As an average then, through the year 2000, the CPEC's would probably contribute no more than 6 million t/yr towards production of manganese ferroalloys, discounting low-grade production used for blast furnace additions.

With respect to the above estimates and assumptions, world cumulative ore and concentrate requirements 1989-2000 are shown in table 9 (the CPEC production is shown as a constant 6 million t/yr or a total of 72 million tons for 12 years). As shown, cumulative MEC share of the market through the year 2000 would require mining a total of 282 million tons of ore at a 0.7% demand increase, to 317 million tons at a 2.0% demand increase. Comparing this with resources shown in table 3, this level of production would use from 24% to 27% of the demonstrated resources and from 16% to 18% of the identified resources, respectively.

The indication is that, based on these estimates, demonstrated resources would last to roughly the year 2035 at an average annual production increase of 0.7%/yr, while identified resources would last to beyond the year 2047. At the other end of the scale (2%/yr), demonstrated resources would be depleted shortly after the year 2023, and identified resources would last to beyond 2035.

Table 9.—Cumulative world manganese production, 1989-2000 at various growth rates (million tons, unless otherwise noted)

% Growth rate	Cumulative Mn conc. production[1]	Consumed in ferro-alloy production[2]	CPEC share[3]	Residual MEC share	MEC raw ore demand[4]
0.7	284	213	72	141	282
1.2	293	220	72	148	295
1.6	300	225	72	153	306
2.0	308	231	72	159	317

[1] Cumulative production calculated based on the formula:

CP = A(e^[r*T]-1)/r,

where CP = cumulative production from base year to target year,

A = base year production (1987),

r = growth rate,

T = number of years.

[2] Assumes 75% of total Mn conc. is used for ferroalloy production.

[3] Assumes 6 million tons/yr constant CPEC concentrate production for ferroalloys.

[4] Assumes 2 tons raw ore to produce 1 ton concentrate.

Production capacity increases, to meet the increase in world demand, will most likely come from countries that are mining the large resource ore bodies. It is unlikely that any of the other countries would contribute significant extra output. This implies that any major future expansion would occur in Australia, Gabon, and South Africa. There are a total of six producing mines in these countries; one each in Australia and Gabon and four in South Africa. With the increase in demand that has occurred in 1988, expansion of these mines may already be under consideration.

These operations could meet the "projected" demand with normal expansion procedures, although the supply/demand relationship would probably not be smooth. A usual sequence of expansion begins with an increase in demand, followed by expansions and over capacity, until supply catches up with demand.

Expansion of manganese ferroalloy production facilities would probably take place in the ore producing countries and/or countries with low power and labor rates. Australia, Brazil, and South Africa would more than likely see expansions.

INDUSTRY ASPECTS

SUPPLY DISRUPTION

Disruption of supply from any major manganese concentrate source would cause at least a temporary shortage, until available mining operations could increase capacity. As stated previously, manganese resources are abundant but are located in a comparatively small number of orebodies. It is not likely that disruption would initiate production from any undeveloped deposits.

Any manganese concentrate supply disruption would also produce downstream effects of smelting inefficiencies and possibly lower quality ferroalloys. Manganese ore is not concentrated to the extent of controlling other constituents, such as, iron, silica, alumina, phosphorus, etc. The concentrates essentially are crushed and washed "raw ore," each with its own unique chemical and physical character. Obtaining optimum quality for efficient smelting, therefore, requires blending of a number of concentrates. Assuming the current MEC manganese concentrate distribution to smelters is in balance with regard to the various contained elements, elimination of a major supply, whose constituent elements have been part of the balance, would obviously have a deleterious effect on downstream processes.

BENEFICIATION RECOVERIES

Another aspect of the industry, which could become important in the future, is low beneficiation recoveries experienced in many operations. Low recoveries are mainly the result of fines (minus 6 mm) either occurring in the raw ore or generated during handling. As much as 2.5 tons of raw ore can be used to produce 1 ton of concentrate. In general, an average of 1.5 to 2 tons of raw ore, to produce 1 ton of concentrate is not uncommon, and a 60% to 70% manganese recovery is about the industry average. Calculated beneficiation recoveries at various ore grades and ore to concentrate ratios are illustrated in table 10.

Table 10.—Manganese recovery rates, based on grade of ore and ore to product ratio[1] (%)

Manganese ore grade	Ore to product ratios			
	1.3:1	1.5:1	2.0:1	2.5:1
38	97	84	63	51
40	92	80	60	48
42	88	76	57	46
44	84	73	55	44
46	80	70	52	42

[1] Recovery rates based on the formula:

$$\frac{\text{Mn content of product}}{(\text{Mn ore grade * ore to product ratio}).}$$

In some operations, fines become mixed with low-grade or barren clay material. When this happens, upgrading the material to market specifications is quite difficult. This material is usually "stockpiled" for future use and may contain in the order of 20% to 35% Mn. In operations where ore does not contain much clay material, the grade of the fines is closer to the final product grade and can sometimes be converted to a marketable lump by sintering.

To overcome low recoveries during beneficiation, the industry would need to invest in more complex metallurgical processes in some cases, and, most certainly, sintering capacity would have to be increased, to make the fine material usable. In total, annual MEC sintering capacity is about 1.5 million tons out of approximately 13 to 14 million tons of MEC concentrate capacity or a little over 10% of concentrate capacity. In view of all the fines currently being wasted, concentrate production could probably be increased by at least another 25% through sintering, without depleting additional resources.

The history of the industry, however, has been mainly one of intense competition, with occasional short periods of high demand. During highly competitive times, there is no incentive for producers to invest in more complex beneficiating processes to improve recoveries. The converse seems to be that in the periods of high demand producers tend to operate at a level that will maximize revenues, possibly at a risk of even lower recoveries.

CONCLUSIONS

The world's manganese supply will continue to be furnished by a few major deposits for many years. There are no known potential resources that could conceivably compete economically with currently producing mines. During periods of over-supply, the producers are in intense competition and prices can fall; however, it is not likely that a price decrease would cause a complete shutdown of a major mine, since the smelting industry is dependent on a wide variety of manganese concentrates. During periods of high demand, prices may increase, which inherently improves the revenue of the producers. There are no new resources that could be economically developed outside of the known ore bodies, regardless of price. Producing deposits are capable of increasing production by normal expansion at a lower cost than would be required for developing a new deposit.

Transportation costs will continue to be the main element of total production costs, and facility support will be the major element of mine site costs.

Resources evaluated amount to about 1.1 billion tons of in situ ore containing 474 million tons of manganese. Additionally, there are an estimated 637 million tons of inferred resources located on currently producing properties that would be available through additional development.

Under projected demand scenarios, annual requirements for manganese ore and concentrates used for ferroalloy production could range from 24.8 million tons to 29.4 million tons by the year 2000. In terms of total cumulative production, manganese ore consumed through the year 2000 could amount to 282 to 317 million tons, or 24% to 27% of the demonstrated resources used in this study. It is quite possible that the MEC's will need to supply a greater percentage of the manganese requirement of the CPEC's in the future, since the quantity and quality of CPEC ores are declining.

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APPENDIX A.—TABLE A-1.— MARKET ECONOMY COUNTRY MANGANESE FERROALLOY SMELTERS, CAPACITIES IN THOUSAND TONS

Country/plant	Owner/operator	Capacity[1]		
		HCFeMn	MCFeMn/ LCFeMn	SiMn
Australia: Bell Bay	Tasmanian Electrometallurgical (BHP)	115	-	60
Belgium: Ghent	Sadacem NV	[2]110	-	-
Brazil:				
Aruja	Prometal Productos Metalurgicas	13	5	15
Barbacena	Cia Paulista de Ferro-Ligas	17	5	36
Caxambu	. . do.	2	5	22
Curumba	. . do.	13	5	15
Itapeva	Cia de Cimento Portland Maringo	12	5	9
Ouro Preto	Cia Paulista de Ferro-Ligas	-	5	15
Simoes Filho (Sibra)	. . do.	[2]77	5	15
Canada:				
Beauharnois	Chromasco Ltd.	-	5	15
. . Do.	Elkem A/S	[2]130	-	-
Chile: Coquimgo	Manganesos Atacama	-	5	15
France:				
Boulogne (BF)	Ste du Ferromanganese de Paris Outreau	400	-	-
Dunkirk	Pechiney	-	5	50
Giffre	. . do.	-	35	5
Germany:				
Duisburg (BF)	Thyssen Stahl AG	240	5	80
Laufenberg	Hermann C. Stark		shut down	
Peine-Saltzgitter	Stahlwerke Peine-Saltzgitter	30	5	15
India:				
Nagpur	Khandelwal Ferro Alloy & Ltd.	20	-	10
Chandrapur	Maharashtra Elektrosmelt Ltd.	67	-	-
Joda	Tata Iron and Steel Co., Ltd.	20	-	5
Komptee		18	-	-
Rayagada	Jeypore Sugar Co., Ltd.	18	-	-
Shreeamnagar	Ferro-Alloys Corp., Ltd.	30	-	-
Tumsar/Uniferro	International Ltd.	60	-	-
Tumsar/Universal	Ferro & Allied Chemicals Ltd.	100	-	10
Italy:				
Bagnolo	Italghisa SpA	NA	-	-
Breno	Carlo Tassarna SpA	20	-	35
Cairo	Elettrosiderurgica Italiana	15	-	-
Sellero	Fucinati SpA	15	-	-
Japan:				
Hachinoe	Pacific Metals Co., Ltd.	50	20	20
Kakogawa	Kobe Steel Co., Ltd.	70	-	50
Kashima	Chou Denki Kogyo Co., Ltd.	90	20	60
Mizushima (EF)	Mizushima Ferro-Alloy Co., Ltd.	100	-	50
(BF)	. . do.	100	20	-
Niigata	Nippon Kokan KK	120	90	100
Takoaka	Japan Metals & Chemicals Co., Ltd.	70	-	120
Tokoshima	Nippon Denko KK	70	-	90
Korea (ROK):				
	Dongba Industrial	50	12	30
	Dongil Ferroalloy Co.	16	4	25
	Korea Ferroalloy Co.	25	-	30
Mexico:				
Gomez Palacio	Ferroaleaciones de Mexico	20	-	15
Tamos	Compania Minera Autlan	100	30	35
Tezuitlan	. . do.	-	-	35
Veracruz	Ferralver	6	-	4
Norway:				
Porsgrunn	Elkem A/S	70	30	40
Kvinesdal	Tinfos Jernverk A/S	-	-	120
Sauda	Elkem A/S	55	75	65

See explanatory notes at end of table.

TABLE A-1.—MARKET ECONOMY COUNTRY MANGANESE FERROALLOY SMELTERS, CAPACITIES IN THOUSAND TONS—Continued

Country/plant	Owner/operator	Capacity[1]		
		HCFeMn	MCFeMn/ LCFeMn	SiMn
Peru: Chimbote	Electrometalurgical Nacional SA	5	-	2
Portugal: Setabul	Eurominas Electro Metalurgia Sarl		shut down	
South Africa, Republic of:				
Cato Ridge	Ferroalloys Ltd.	[2]165	-	-
Meyerton	Ferrometals Ltd.	510	-	165
Witbank	Transalloys Ltd.	53	-	135
Spain:				
Cee	Sdad Espanola De Carburos Metalices SA	45	-	25
Ferro	Ferroaleaciones y Carburos	50	12	40
Hidro	Hidro Nitro Espanola SA	-	40	20
Taiwan:				
Taipei	Chen Hsing Industrial Co., Ltd.	[2]25	-	-
Keelung	Chou Iron and Steel Co., Ltd.	NA	-	-
Ping Chen	Tung Chou Industrial Co., Ltd.	[2]32	-	-
San Yen	Taiwan Steel & Mining Corp.	[2]24	-	-
United Kingdom:				
Middleborough	British Steel Corp.	125	-	-
United States:				
Marietta	Elken A/S	[2]130	-	-
Venezuela:				
Puerto Ordaz	Compania Minera Autlan (Mexico)	-	-	20

NA Not available.

(EF): Electric Furnace.

(BF): Blast Furnace.

[1] Estimated capacities may vary, since smelters can change products depending on markets.

[2] Effective HCFeMn, that is if the smelter was dedicated to HCFeMn only.

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