BUREAU OF MINES
INFORMATION CIRCULAR/1994

Manganese Material Flow Patterns

By Thomas S. Jones

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mt/yr	metric ton per year
g	gram	st	short ton
km	kilometer	st/yr	short ton per year
mt	metric ton		

Unless indicated otherwise, the weight unit used in this report is the short ton of 2,000 pounds. This unit was chosen because it is the unit predominantly used in U.S. Bureau of Mines publications on manganese for data prior to 1992. Therefore, historical data given in this report can be compared directly with those previously published. In a few instances, particularly in the section on natural manganese flows and the effect of human activities upon them, metric tons have been used because the original sources were in metric tons.

MANGANESE MATERIAL FLOW PATTERNS

By Thomas S. Jones[1]

ABSTRACT

This report discusses processing and use of the principal forms of manganese. The focus is on trends in the United States in the 20th century and specifics of domestic manganese material flows as of about 1990. To protect proprietary data, quantitative assessments are limited to the iron and steel industry, which accounts for about 90% of consumption. Nonmetallurgical uses are considered qualitatively.

Approximate disposition of a U.S. cumulative consumption during 1901-90 of an estimated 69 million st of manganese is estimated to be iron and steel slag, 69%; nonmetallurgical uses of a dissipative nature, 10%; iron and steel scrap, 9%; National Defense Stockpile, 3%; unidentified and/or including items in service, 10%.

In slag from iron blast furnaces and steelmaking, manganese is present as a minor, relatively immobile component, which so far has been uneconomical to recover. Construction and road building are main applications for these slags. Steel slag contains the greater amount of manganese.

Studies by others of global manganese fluxes and the effect of human activities on them also are discussed. One source concludes that the main effect of human activities, via deforestation and agricultural activities, has been to increase the rate of transport of manganese to the oceans.

[1]Physical scientist, U.S. Bureau of Mines, Washington, DC.

INTRODUCTION

Manganese, Mn, is a metal that is a member of Group VII of the periodic system of the elements and has an atomic number of 25 and an atomic weight of 54.94. Manganese is bounded within the periodic system on the Group VI side by chromium and on the Group VIII side by iron, cobalt, and nickel. From a chemical standpoint, manganese is related very closely to iron. From a metallurgical standpoint, manganese differs from iron and iron's atomic neighbors in that, although iron, cobalt, and nickel possess useful physical properties as relatively pure metals and readily serve as the basis of alloy systems, manganese does not. The explanation for the difference is that, under normal conditions, the arrangement of the atoms in the manganese crystal structure is such that manganese is typically a brittle and unworkable material. On the other hand, manganese performs very useful functions when alloyed with iron (as in steel) and with aluminum and other nonferrous metals. Thus, in its principal applications, manganese serves as an alloying element.

Manganese is also used in nonmetallic form, chiefly as oxides such as manganese dioxide (MnO_2) and manganous oxide (MnO). The principal ore minerals consist of these oxides combined with oxides of other elements so as to form, for example, oxysilicates such as in braunite [$3(Mn,Fe)_2O_3 \cdot MnSiO_3$]. Another important type of natural occurrence of manganese is as a carbonate: rhodochrosite ($MnCO_3$) if pure but commonly impure as a mixed carbonate. Natural ore, generally after having been beneficiated into a concentrate, is used to incorporate manganese into the charge to a blast furnace for making pig iron. More importantly, as shown in figure 1, ore serves as the source of manganese units for smelting manganese ferroalloys and manufacturing the metal and various chemicals. Synthetic dioxide, in particular electrolytic manganese dioxide (EMD), is perhaps the most important chemical product. Manganese sulfate ($MnSO_4$) is a widely employed intermediate in manganese processing and is used also in animal feed and plant fertilizer.

A myriad of uses of manganese other than in steelmaking accounts for only a minor part of manganese consumption. Natural and synthetic dioxide are used in dry cell batteries as well as in soft ferrites. Manganous oxide, manganese sulfate, and manganese oxysulfate (chemical and physical combinations of the oxide and sulfate) are used in animal feed and plant fertilizer. Potassium permanganate ($KMnO_4$) is a strong oxidizing agent used for water treatment and other purposes. Collectively, the amount of domestic consumption of manganese attributable to nonmetallurgical uses can be estimated to have been in the range of 5% to 10%, with the balance of 90% or more attributable to steelmaking and other metallurgical uses.

The discussion that follows deals with the evolution of the manganese industry in the United States and certain environmental aspects of manganese use. This treatment for manganese constitutes one of a series of studies that the U.S. Bureau of Mines has initiated on the flow of materials resulting from the production and use of various commodities. Flow patterns as of 1988 are indicated schematically in figure 1 for ore extraction up to the points at which various industries consume manganese in the form(s) suitable for them. Further specifics are given in figure 2. These flow patterns are assumed also to approximate closely conditions in 1990. Additional information and details, as noted, are presented in appendix A. An overview of the manganese industry in foreign countries as of about 1990 is given in appendix B.

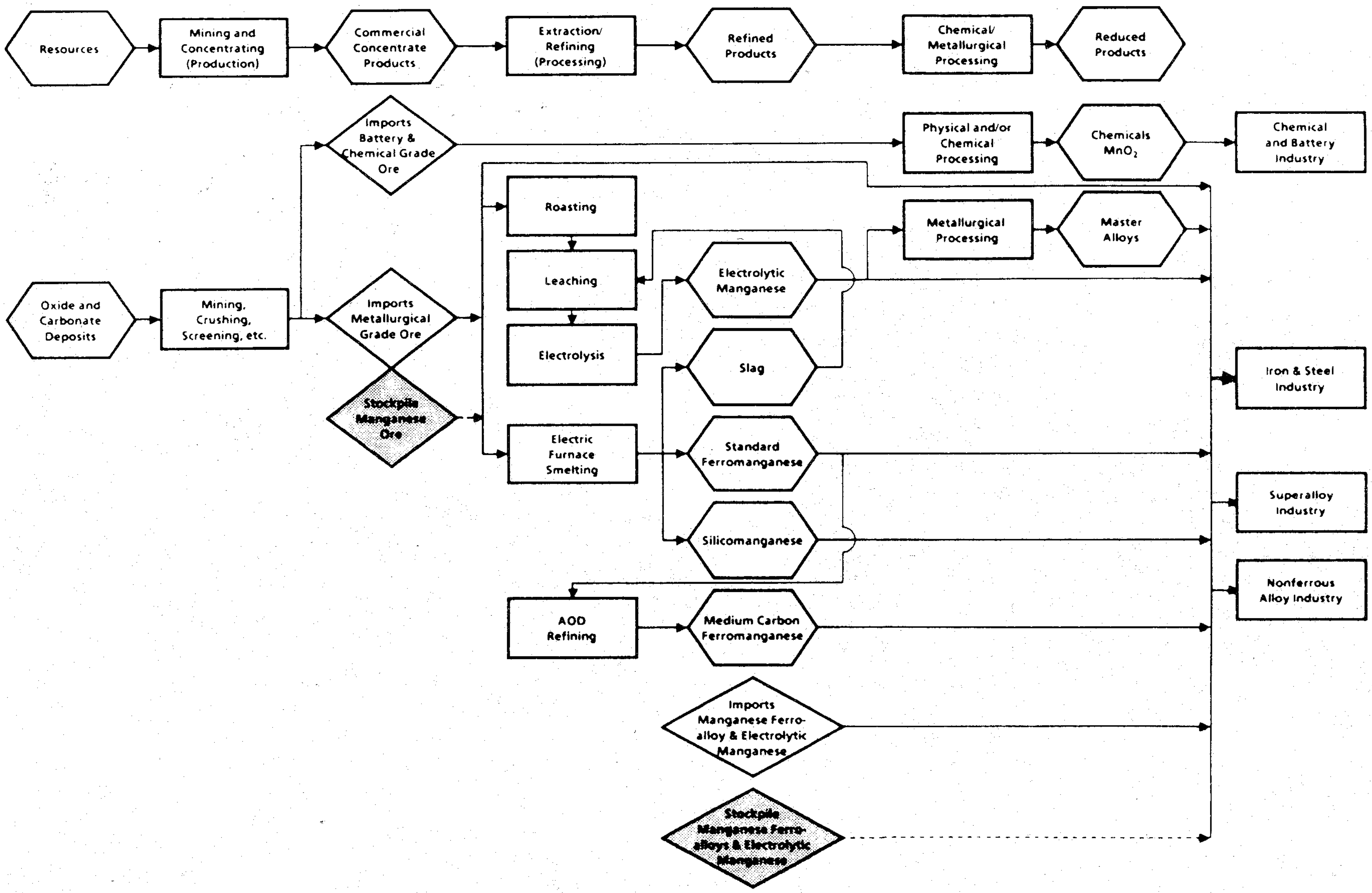
ACKNOWLEDGMENTS

The author would like to thank Mr. H. G. Goehring, Staff Engineer, Elkem Metals Co., Marietta, OH; Professor R. D. Pehlke, Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI; and Dr. J. R. Stubbles, Manager of Technology, Charter Steel Co., Saukville, WI, for their reviews of the manuscript and constructive suggestions.

MANGANESE PRODUCTION AND UTILIZATION IN THE UNITED STATES

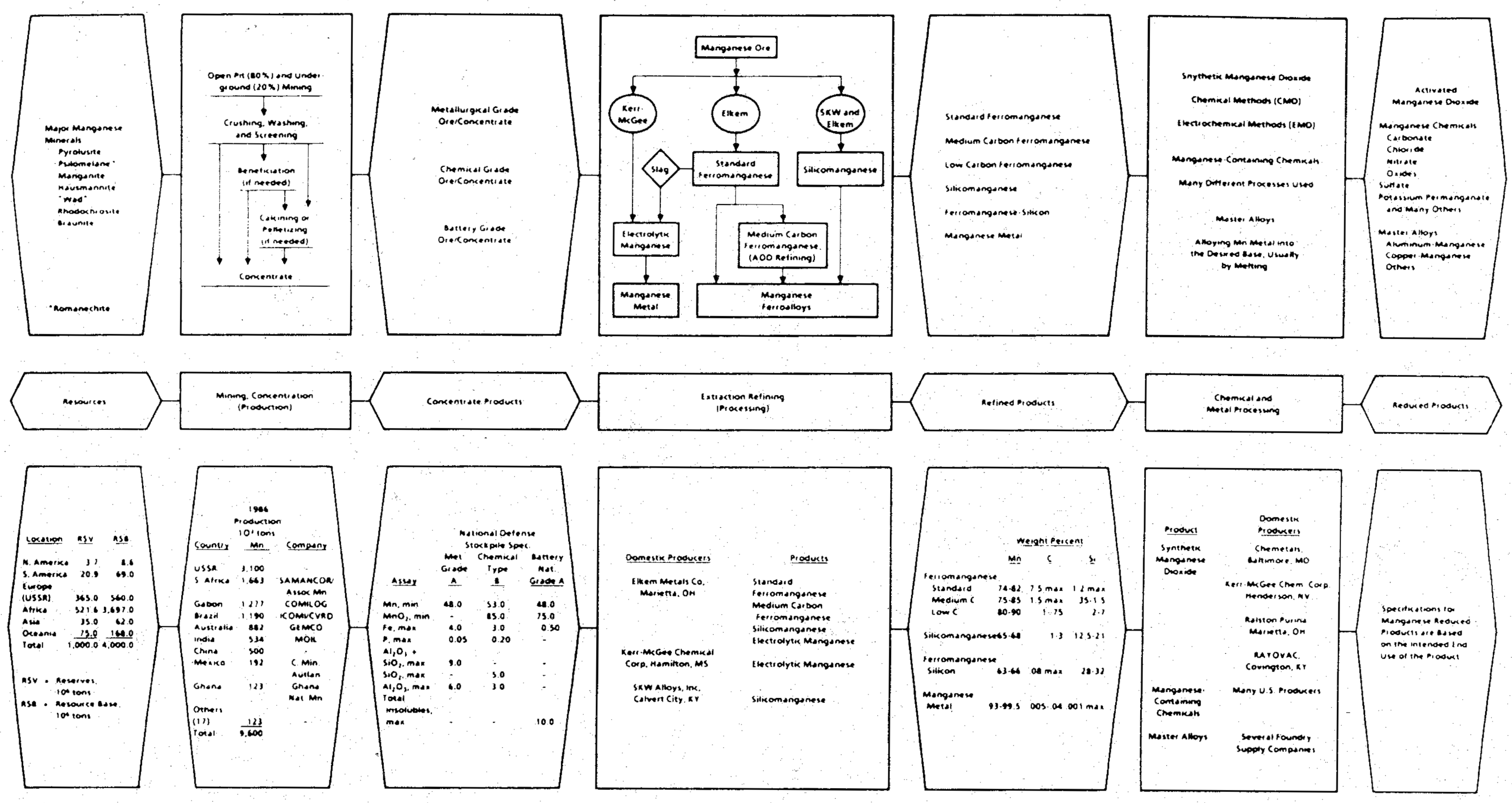
ORE

The United States has not been a significant factor in manganese ore production because of a lack of sizable deposits of high-grade ore. During periods of national emergency or in response to the problems associated with them, the Federal Government has stimulated domestic mining for manganese and encouraged development of foreign deposits. As noted in a report of the National Materials Advisory Board (NMAB), "...since the turn of the



Source: Battelle-Columbus Div., Columbus, OH (sponsored by Industrial Materials Div., Wright-Patterson AFB, OH). Manganese for Superalloys, July 1988, figure II-2.

Figure 1.—Flow diagram for manganese in selected domestic industries.



Location	RSV	RSB
N. America	3.7	8.6
S. America	20.9	69.0
Europe (USSR)	365.0	540.0
Africa	521.6	3,697.0
Asia	35.0	62.0
Oceania	75.0	168.0
Total	1,000.0	4,000.0

RSV = Reserves, 10⁶ tons
RSB = Resource Base, 10⁶ tons

Country	1986 Production 10³ tons Mn	Company
USSR	3,100	
S. Africa	1,663	SAMANCOR/ Assoc Mn
Gabon	1,277	COMILOG
Brazil	1,190	ICOMI/CVRD
Australia	882	GEMCO
India	534	MOIL
China	500	-
Mexico	192	C. Min Autlan
Ghana	123	Ghana Nat. Mn
Others (17)	123	-
Total	9,600	

Assay	Met Grade A	Chemical Type B	Battery Nat. Grade A
Mn, min	48.0	53.0	48.0
MnO₂, min	-	85.0	75.0
Fe, max	4.0	3.0	0.50
P, max	0.05	0.20	-
Al₂O₃ + SiO₂, max	9.0	-	-
SiO₂, max	-	5.0	-
Al₂O₃, max	6.0	3.0	-
Total insolubles, max	-	-	10.0

(National Defense Stockpile Spec.)

	Weight Percent Mn	C	Si
Ferromanganese Standard	74-82	7.5 max	1.2 max
Medium C	75-85	1.5 max	.35-1.5
Low C	80-90	.1-.75	2-7
Silicomanganese	65-68	1-3	12.5-21
Ferromanganese Silicon	63-66	.08 max	28-32
Manganese Metal	93-99.5	.005-.04	.001 max

Source: Battelle-Columbus Div., Columbus, OH (sponsored by Industrial Materials Div., Wright-Patterson AFB, OH). Manganese for Superalloys, July 1988, figure II-1.

Figure 2.—Profile of domestic manganese industry.

century, domestic production rarely has exceeded a few percent of annual consumption. Under wartime stimulus and with a variety of incentive programs, domestic production amounted to 23 percent of consumption during the 1916-1920 period (World War I), 13 percent in the 1941-1945 period (World War II), and 8 percent in the 1951-1955 period (Korean emergency)" (*1*, p. 11).[2] The record underlying this statement is illustrated in figure 3, which also shows that imports of ore have been much more important than domestic production.

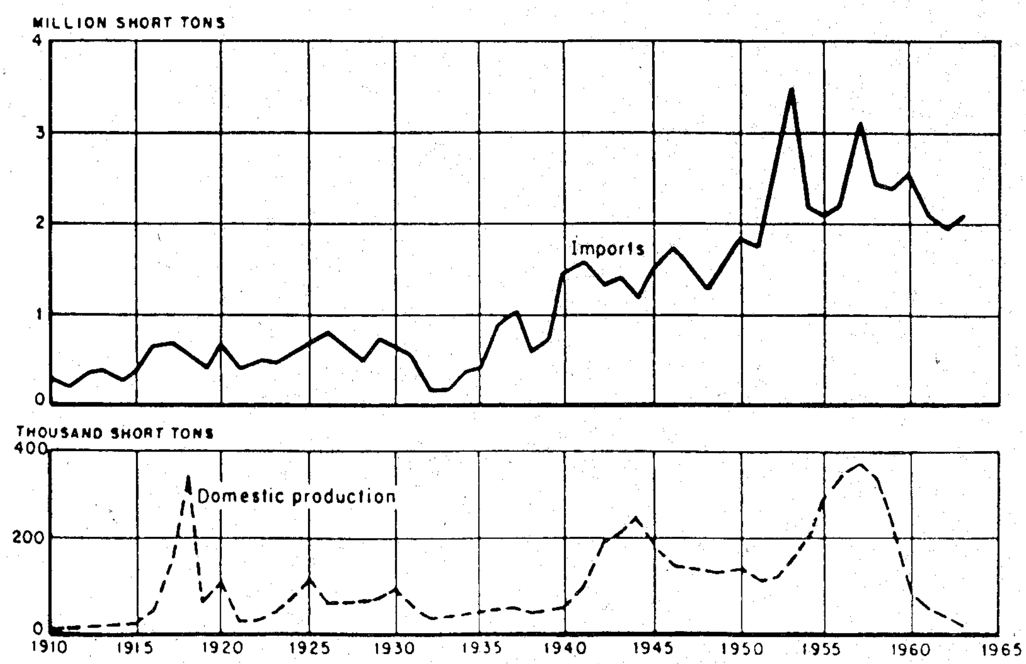
Selected data on historical domestic production of ore are listed in table 1 categorized by manganese content according to the conventions generally used in Bureau of Mines statistics: 35% or more, manganese ore; 10% to 35%, ferruginous manganese ore; and 5% to 10%, manganiferous iron ore. Data for manganese content are lacking for years prior to 1941, but, assuming the same contents before and after content data became available, it can be estimated that domestic production of manganese ore has supplied a maximum of nearly 3 million tons of manganese in the 20th century. The leading source of shipments of manganese ore was Montana, from which shipments ended in 1973. On the same basis, it can be estimated that the maximum supply of manganese from domestic shipments has approached 4 million tons for ferruginous manganese ore and more than 2 million tons for manganiferous iron ore; for both, Minnesota was the leading source. These data and the estimates based on them indicate that during 1900-90 the manganese supplied from domestic sources may have totaled as much as 8.8 million tons, or approximately 13% of a cumulative U.S. apparent consumption estimated as about 69 million tons for the same period.

Following World War II, the Government built up a sizable stockpile of manganese materials. For example, the inventory of all types of foreign and domestically produced ore approached, on the basis of gross weight, 11 million tons in 1969, but has declined since for several reasons. This decline has included sales of excesses of ore and, since the mid-1980's, a Government program of upgrading ore into ferromanganese. As of the end of 1990, ore in Government inventories consisted of about 1,800,000 tons of stockpile-grade material, less than 900,000 tons of nonstockpile-grade material, and about 16,000 tons of ore that had been sold but not yet shipped.

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

IRON AND STEEL INDUSTRY

As already mentioned, the iron and steel industry accounts for the lion's share of manganese consumption, typically around 90% or more. Steps that usually occur in steelmaking are indicated schematically in figure 4, which is from a 1985 report of the U.S. Congressional Office of Technology Assessment (OTA) (*2*). Crosshatching has been used to identify the routes by which manganese enters processing sequences.



Source: Manganese chapter in U.S. Bureau of Mines Minerals Yearbook, 1963, p. 779.

Figure 3.—General imports and domestic production (shipments) of manganese ore, 1910-63.

Table 1.—Manganese and manganiferous ores shipped by mines in the United States, 1838-1990

(Thousand short tons)

Year	>35% Manganese: Total[1] Gross weight	>35% Manganese: Total[1] Content	Principal states, gross weight: Arizona	Arkansas	California	Georgia	Montana	Nevada	Virginia	10% to 35% Manganese: Total[1] Gross weight	10% to 35% Manganese: Total[1] Content	Minnesota Gross weight	New Mexico Gross weight	5% to 10% Manganese: Total[1] Gross weight	5% to 10% Manganese: Total[1] Content	Minnesota Gross weight
1838-99	384	NA	—	55	12	90	—	(2)	217	NT	NT	NT	NT	NT	NT	NT
1900	13	NA	—	(2)	(2)	4	(2)	—	9	634	NA	[3]374	(4)	(4)	(4)	(4)
1901	13	NA	—	(2)	1	5	—	—	5	899	NA	[3]574	(4)	(4)	(4)	(4)
1902	8	NA	—	(2)	1	4	—	—	3	1,227	NA	[3]991	(4)	(4)	(4)	(4)
1903	3	NA	—	—	(2)	1	—	—	2	855	NA	[3]635	(4)	(4)	(4)	(4)
1904	4	NA	—	—	(2)	—	—	—	3	547	NA	[3]409	(4)	(4)	(4)	(4)
1905	5	NA	—	—	(2)	(2)	—	—	4	953	NA	[3]807	(4)	(4)	(4)	(4)
1906	8	NA	—	(2)	(2)	—	—	—	7	1,166	NA	[3]1,120	(4)	(4)	(4)	(4)
1907	6	NA	—	—	(2)	—	—	—	5	476	NA	[3]352	(4)	(4)	(4)	(4)
1908	7	NA	—	—	—	—	—	—	7	586	NA	[3]523	(4)	(4)	(4)	(4)
1909	2	NA	—	—	—	—	—	—	2	945	NA	[3]868	(4)	(4)	(4)	(4)
1910	3	NA	—	1	—	—	—	—	2	694	NA	[3]626	(4)	(4)	(4)	(4)
1911	3	NA	—	—	(2)	—	—	—	3	585	NA	[3]535	(4)	(4)	(4)	(4)
1912	2	NA	—	—	(2)	—	—	—	2	973	NA	[3]915	(4)	(4)	(4)	(4)
1913	5	NA	—	—	—	—	—	—	5	753	NA	[3]696	(4)	(4)	(4)	(4)
1914	3	NA	—	—	1	—	—	—	2	499	NA	[3]451	(4)	(4)	(4)	(4)
1915	11	NA	(2)	1	3	4	—	(2)	2	203	NA	48	(4)	17	NA	(4)
1916	35	NA	3	7	7	(5)	7	(5)	5	508	NA	216	18	101	NA	53
1917	145	NA	17	11	16	4	68	4	14	818	NA	403	18	146	NA	103
1918	343	NA	20	9	27	7	224	22	12	1,026	NA	707	37	285	NA	257
1919	62	NA	1	3	13	(2)	28	(2)	4	347	NA	156	14	139	NA	120
1920	106	NA	3	4	2	(2)	86	1	3	539	NA	329	22	321	NA	279
1921	15	NA	(2)	1	—	—	12	—	1	9	NA	—	—	70	NA	63
1922	15	NA	(2)	3	(5)	—	11	(5)	1	386	NA	342	32	282	NA	278
1923	35	NA	(2)	4	(5)	2	25	—	1	358	NA	284	8	1,201	NA	559
1924	63	NA	(2)	4	1	1	40	1	2	321	NA	179	26	657	NA	405
1925	110	NA	(2)	4	1	2	85	1	3	299	NA	87	46	1,292	NA	830
1926	52	NA	3	3	(2)	4	26	2	4	408	NA	178	58	936	NA	895
1927	50	NA	4	3	—	1	30	2	4	166	NA	7	63	1,467	NA	1,047
1928	52	NA	4	4	—	5	30	—	4	101	NA	4	41	1,216	NA	1,148
1929	68	NA	3	5	1	3	47	—	3	88	NA	6	—	1,243	NA	1,125
1930	75	NA	(2)	4	(2)	21	40	2	4	87	NA	5	—	793	NA	777
1931	44	NA	—	5	(2)	7	29	—	2	72	NA	30	—	243	NA	243
1932	20	NA	—	1	—	(2)	17	—	1	18	NA	2	—	11	NA	—
1933	21	NA	—	2	—	2	10	—	5	14	NA	—	—	200	NA	192
1934	30	NA	—	7	(2)	7	13	—	2	26	NA	—	—	222	NA	221
1935	30	NA	—	4	—	8	12	—	3	104	NA	87	—	483	NA	470
1936	36	NA	—	5	—	4	18	—	2	111	NA	54	(2)	943	NA	942
1937	45	NA	—	4	—	1	30	—	3	170	NA	94	21	1,332	NA	1,314
1938	28	NA	—	3	—	3	13	(2)	3	38	NA	20	7	308	NA	290
1939	33	NA	—	6	(2)	3	12	—	2	268	NA	204	36	526	NA	526
1940	45	NA	(2)	7	(2)	4	22	(2)	2	358	NA	279	41	915	NA	893
Total[6]	1,653	NA	60	114	73	106	937	36	151	18,637	NA	13,595	487	15,348	NA	13,032

See footnotes at end of table.

Table 1.—Manganese and manganiferous ores shipped by mines in the United States, 1838-1990—Continued

(Thousand short tons)

Year	>35% Manganese									10% to 35% Manganese				5% to 10% Manganese		
	Total[1]		Principal states, gross weight							Total[1]		Minnesota	New Mexico	Total[1]		Minnesota
	Gross weight	Content	Arizona	Arkansas	California	Georgia	Montana	Nevada	Virginia	Gross weight	Content	Gross weight	Gross weight	Gross weight	Content	Gross weight
1941	88	44	1	5	4	5	55	3	5	512	69	410	65	919	63	918
1942	191	102	3	4	13	5	130	6	11	269	43	89	89	1,501	120	1,500
1943	205	109	6	5	23	2	138	10	7	472	68	254	73	1,251	95	1,251
1944	248	132	9	7	22	1	160	22	20	297	47	123	101	1,190	91	1,145
1945	182	103	1	7	2	1	152	1	9	114	17	—	86	1,409	97	1,407
1946	144	84	—	1	—	—	138	1	1	100	16	—	72	1,071	68	1,071
1947	132	77	(2)	1	—	—	130	(2)	—	129	20	—	97	1,045	63	1,045
1948	131	76	(2)	(2)	—	—	130	—	(2)	142	18	—	123	1,199	72	1,199
1949	126	71	(2)	3	(2)	—	122	—	(2)	26	6	3	—	1,052	63	987
1950	134	77	(2)	1	(2)	—	131	—	(2)	115	16	16	74	972	59	854
1951	105	59	(2)	4	—	—	101	(2)	—	106	13	15	80	1,066	65	996
1952	115	62	(2)	2	8	—	100	1	1	106	14	32	53	903	52	881
1953	158	83	—	6	5	—	113	20	8	273	36	201	—	967	56	890
1954	206	98	—	14	1	—	59	—	23	62	12	8	21	497	28	497
1955	287	145	1	24	3	—	106	101	33	162	21	115	40	749	44	749
1956	345	165	42	29	7	—	81	121	20	141	17	94	39	540	35	540
1957	366	170	80	23	9	—	68	129	13	250	30	201	43	615	38	491
1958	327	[e]149	62	22	18	—	53	127	8	88	11	50	—	433	26	320
1959	229	99	68	18	19	2	22	57	6	164	21	123	—	306	20	306
1960	80	39	2	—	—	—	29	49	—	91	13	54	—	567	37	387
1961	46	21	—	—	—	—	18	29	—	118	15	92	—	107	9	90
1962	25	13	—	—	—	—	25	—	—	193	25	147	—	146	9	146
1963	11	5	—	—	—	—	5	—	—	390	48	347	41	153	9	—
1964	26	13	—	—	—	—	20	—	—	208	26	157	47	31	3	31
1965	29	15	—	—	—	—	24	—	—	296	37	244	50	37	3	37
1966	14	6	—	—	—	—	(5)	—	—	320	43	271	48	5	(2)	5
1967	13	6	—	—	—	—	(5)	—	—	289	41	237	49	—	—	—
1968	11	6	—	—	—	—	5	—	—	243	33	190	51	2	(2)	2
1969	6	3	—	—	—	—	1	—	—	431	60	381	49	(2)	(2)	(2)
1970	5	2	—	—	—	—	1	—	—	368	50	321	46	—	—	—
1971	(2)	(2)	—	—	—	—	(2)	—	—	198	27	170	28	—	—	—
1972	1	(2)	—	—	—	—	1	—	—	147	19	119	28	—	—	—
1973	(2)	(2)	—	—	—	—	(2)	—	—	203	26	171	32	—	—	—
1974	—	—	—	—	—	—	—	—	—	273	35	226	47	—	—	—
1975	—	—	—	—	—	—	—	—	—	159	19	109	50	1	(2)	—
1976	—	—	—	—	—	—	—	—	—	202	26	202	—	54	5	—
1977	—	—	—	—	—	—	—	—	—	196	25	166	29	20	2	—
1978	—	—	—	—	—	—	—	—	—	290	37	253	36	22	2	—
1979	—	—	—	—	—	—	—	—	—	215	29	182	33	26	2	—
1980	—	—	—	—	—	—	—	—	—	154	21	119	35	20	2	—

See footnotes at end of table.

Table 1.—Manganese and manganiferous ores shipped by mines in the United States, 1838-1990—Continued

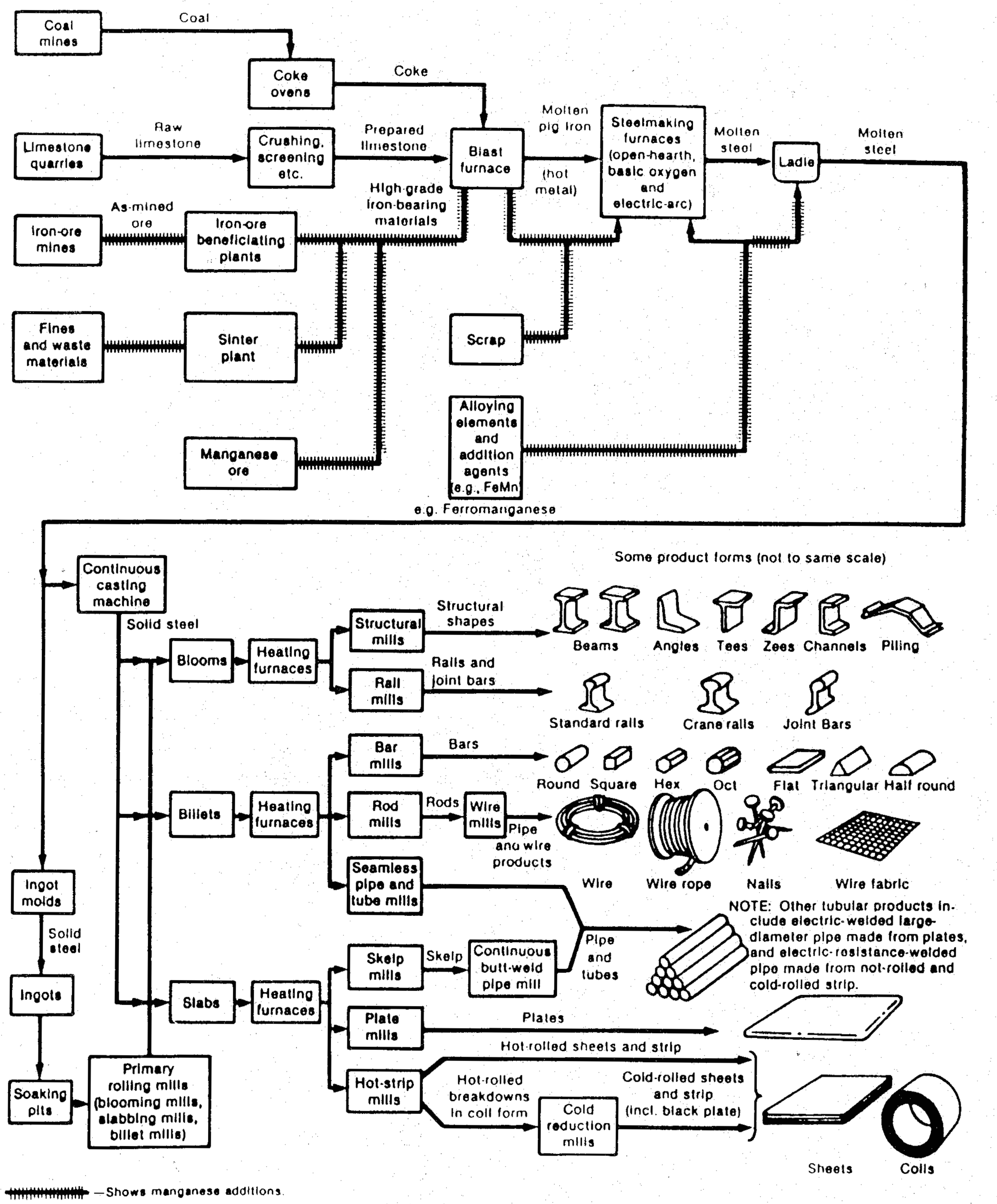
(Thousand short tons)

Year	>35% Manganese									10% to 35% Manganese				5% to 10% Manganese		
	Total[1]		Principal states, gross weight							Total[1]		Minnesota	New Mexico	Total[1]		Minnesota
	Gross weight	Content	Arizona	Arkansas	California	Georgia	Montana	Nevada	Virginia	Gross weight	Content	Gross weight	Gross weight	Gross weight	Content	Gross weight
1981	—	—	—	—	—	—	—	—	—	152	22	140	13	22	2	—
1982	—	—	—	—	—	—	—	—	—	16	3	16	—	15	1	—
1983	—	—	—	—	—	—	—	—	—	11	2	11	—	22	2	—
1984	—	—	—	—	—	—	—	—	—	68	9	68	—	20	2	—
1985	—	—	—	—	—	—	—	—	—	—	—	—	—	20	2	—
1986	—	—	—	—	—	—	—	—	—	—	—	—	—	14	1	—
1987	—	—	—	—	—	—	—	—	—	—	—	—	—	W	W	—
1988	—	—	—	—	—	—	—	—	—	—	—	—	—	W	W	—
1989	—	—	—	—	—	—	—	—	—	—	—	—	—	W	W	—
1990	—	—	—	—	—	—	—	—	—	—	—	—	—	W	W	—
Total[6]	3,986	2,035	276	177	134	16	2,115	678	166	8,761	1,181	6,127	1,768	18,988	1,248	17,743
Grand total[6]	5,639	[7]2,879	335	291	207	122	3,052	714	318	27,398	[7]3,693	19,723	2,255	34,336	[7]2,257	30,775

[e]Estimated NA Not available. NT Not tabulated. W Withheld to avoid disclosing company proprietary data.
[1]Includes all States.
[2]Less than 1/2 unit.
[3]Lake Superior region.
[4]If any ore with 5% to 10% manganese, included with "10% to 35% manganese."
[5]Included within a multi-State total.
[6]Data may not add to totals shown because of independent rounding.
[7]Estimated assuming same average percentage content for 1900-40 as for 1941-90.

NOTES.—Data for fluxing ores in early years: Generally excluded from State data, but may be included in total. Colorado, earliest years: Manganese-silver ores included, but not ores used for fluxing. Dashes indicate zeros.

Source: U.S. Bureau of Mines Minerals Yearbooks: Manganese and Manganiferous Ores (1908-42), Manganese (1943-90).



SOURCE: *The Making, Shaping, and Treating of Steel*, the United States Steel Corp., Pittsburgh, PA, 1971, adapted by the Office of Technology Assessment to show manganese flows.

Source: Reference 2, p. 234.

Figure 4.—Flow diagram showing the principal process steps involved in converting raw materials into the major steel product forms, excluding coated products.

Manganese is ubiquitous in steel and cast iron, originally because of the more or less unavoidable presence of sulfur in the raw materials from which steel and cast iron were and are produced. The metallurgical characteristics of the processes used in commercial production of steel and cast iron are such that at least some sulfur ends up as an impurity in the final products. In the absence of manganese, the sulfur impurity causes hot solid steel undergoing initial shaping to break up, a phenomenon referred to as "hot shortness."

Addition of manganese was found to be an effective and economical way of overcoming this otherwise serious impediment to the making of usable steel articles. Discovery around 1860 of this benefit of a manganese addition was instrumental to realization of tonnage steel production. Manganese is used in steelmaking for more than control of sulfur. Manganese has a stronger affinity for oxygen than iron and therefore can be employed as a mild deoxidizer. Making an alloying addition of manganese also can be an economical way of obtaining in steel any of a number of metallurgical effects, such as increasing strength, toughness, hardness, and/or hardenability. Use of manganese as an alloying element has become increasingly significant as compared with the traditional uses of manganese to control sulfur and oxygen (*3*).

The bulk of manganese consumption in steels is accounted for by four main steel categories, as shown in table 2: primarily carbon; but also stainless and heat-resisting; full alloy; and high-strength, low-alloy. In its 1985 report, OTA assessed the average manganese content of each of these categories of steel as 0.65%, 1.7%, 0.75%, and 1.1%, respectively, and the average manganese content in steel overall as about 0.7% (*2*, pp. 229-232).

Table 2.—U.S. consumption, by end use, and industry stocks of manganese ferroalloys and metal in 1990

(Short tons, gross weight)

End use	Ferromanganese			Silico-manganese	Manganese metal
	High carbon	Medium and low carbon	Total		
Steel:					
Carbon	256,022	87,152	343,174	74,121	(1)
Stainless and heat-resisting	13,897	(1)	13,897	5,117	3,101
Full alloy	34,883	8,612	43,495	18,013	725
High-strength, low-alloy	27,364	5,202	32,566	5,969	(1)
Electric	(1)	(1)	(1)	(1)	(1)
Tool	259	3	262	(1)	46
Unspecified	134	639	773	231	1,815
Total steel[2]	332,559	101,608	434,167	103,451	5,687
Cast irons	12,938	1,000	13,938	1,732	—
Superalloys	W	—	W	—	180
Alloys (excluding alloy steels and superalloys)	950	W	950	W	[3]19,047
Miscellaneous and unspecified	6,067	233	6,300	2,767	510
Total consumption	352,514	102,841	455,355	[4]107,950	25,424
Total manganese content[5]	275,000	82,000	357,000	71,000	25,000
Stocks, Dec. 31:					
Consumers and producers	47,592	13,949	61,541	8,328	3,807

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Withheld to avoid disclosing company proprietary data; included with "Steel: Unspecified."
[2]Includes estimates.
[3]Approximately 90% of this subtotal was for consumption in aluminum alloys.
[4]Internal evaluation indicates that silicomanganese consumption is considerably understated.
[5]Estimated based on typical percent manganese content (rounded).

NOTE.—Dashes indicate zeros.

Source: U.S. Bureau of Mines Commodity Annual Report for Manganese, 1990.

FERROALLOYS AND METAL

Ferromanganese, specifically the high-carbon grade that contains nearly 80% manganese, about 7% carbon, and the balance mostly iron, has been the chief material used to add manganese to steel. Silicomanganese, which typically contains about 18% silicon and 67% manganese, was developed so that a single ferroalloy could be used to obtain the metallurgical benefits of adding silicon and manganese to steel simultaneously. Silicomanganese has become the second most important manganese ferroalloy because of the rise since about 1960 in the relative importance of scrap-based electric furnace steelmaking. High-carbon ferromanganese, also referred to as standard or regular ferromanganese, can be produced using either a blast furnace or an electric furnace of the submerged arc type commonly used also to produce ferroalloys of chromium and silicon. Such electric furnaces are normally used to produce silicomanganese.

Using mostly imported ores, the United States used to be self-sufficient in production of at least the main manganese ferroalloys. The blast furnace was used by merchant producers and by such major steel producers as Bethlehem Steel Co. and the then U.S. Steel Corp. as the predominant method of making high-carbon ferromanganese. As can be seen in figure 5, domestic production of ferromanganese was in decline in the latter 1960's, at which time merchant production was being phased out. By the mid-1970's, the only remaining blast furnace production was that of U.S. Steel and Bethlehem Steel, and this ended when Bethlehem Steel's unit at Johnstown, PA, was flooded in 1977. Since that time, production of manganese ferroalloys has been totally by electric furnace, including a small production by a fused-salt process (Chemetals Inc. at Kingwood, WV) that, in late 1985, also was ended by a flood.

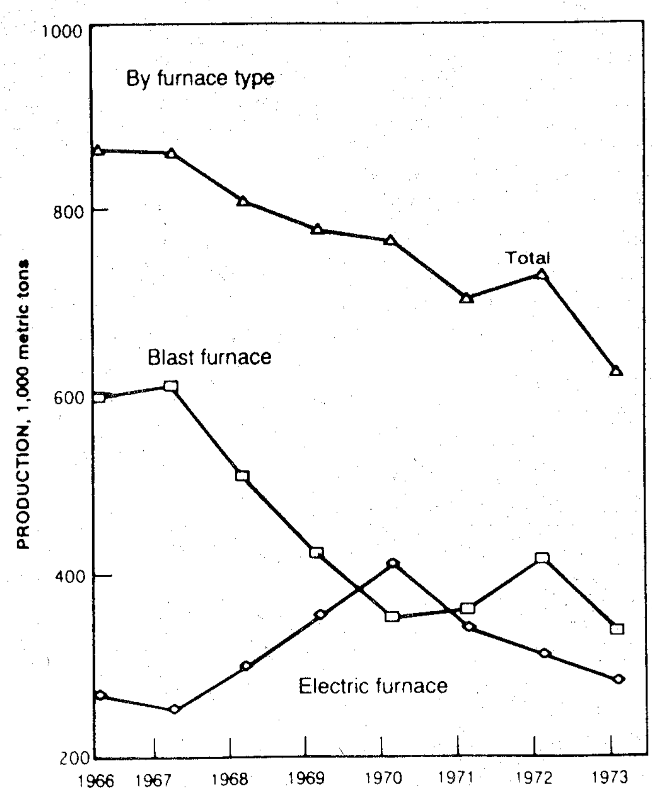


Figure 5.—U.S. production of ferromanganese by furnace type, 1966-73.

With the demise of domestic production of ferromanganese by the blast furnace process, the U.S. demand for manganese ferroalloys has been met not by increased domestic electric furnace capacity but rather by increased imports of ferroalloys. Associated with that trend was a decline in imports of ore. As a result, a changeover occurred in 1977 in the pattern of manganese imports. Prior to that year, the United States had imported the majority of its mineral manganese units as ore. Since then, the majority of manganese units imported have been as ferroalloys and metal. The change can be illustrated by noting that, in 1966, the United States imported more than 2.5 million tons of manganese ore and produced nearly 1.2 million tons of manganese ferroalloys and 134 million tons of raw steel; the contrasting figures for 1980 were imports of about 700,000 tons of manganese ore and production of about 380,000 tons of manganese ferroalloys and 112 million tons of raw steel.

It was announced in 1982 that the Federal Government would initiate a 10-year upgrading program that had the dual objectives of maintaining the domestic manganese ferroalloy industry and decreasing, in the interest of defense readiness, the ore/ferroalloy ratio of the manganese materials in the National Defense Stockpile. Under this program, quantities of ore in the stockpile have been converted domestically into high-carbon ferromanganese, beginning in 1984. From this program's inception through 1990, about 627,000 tons of ore was appropriated for upgrading, and 343,000 tons of ferromanganese was accepted into inventory.

In 1990, Elkem Metals Co. at its Marietta, OH, plant produced ferromanganese and silicomanganese and, as such, was the only domestic producer of manganese ferroalloys. Elkem Metals, at the same plant, and Kerr-McGee Chemical Corp., at its Hamilton, MS, plant, were the only producers of manganese metal.

NONMETALLURGICAL APPLICATIONS

The steps involved in the processing of manganese ore into the main chemical forms in which manganese is used are shown schematically in figure 6. The forms indicated collectively compose roughly one-tenth of manganese consumption and are as follows: manganese dioxide (MnO_2) for manufacture of dry cell batteries, manganous oxide

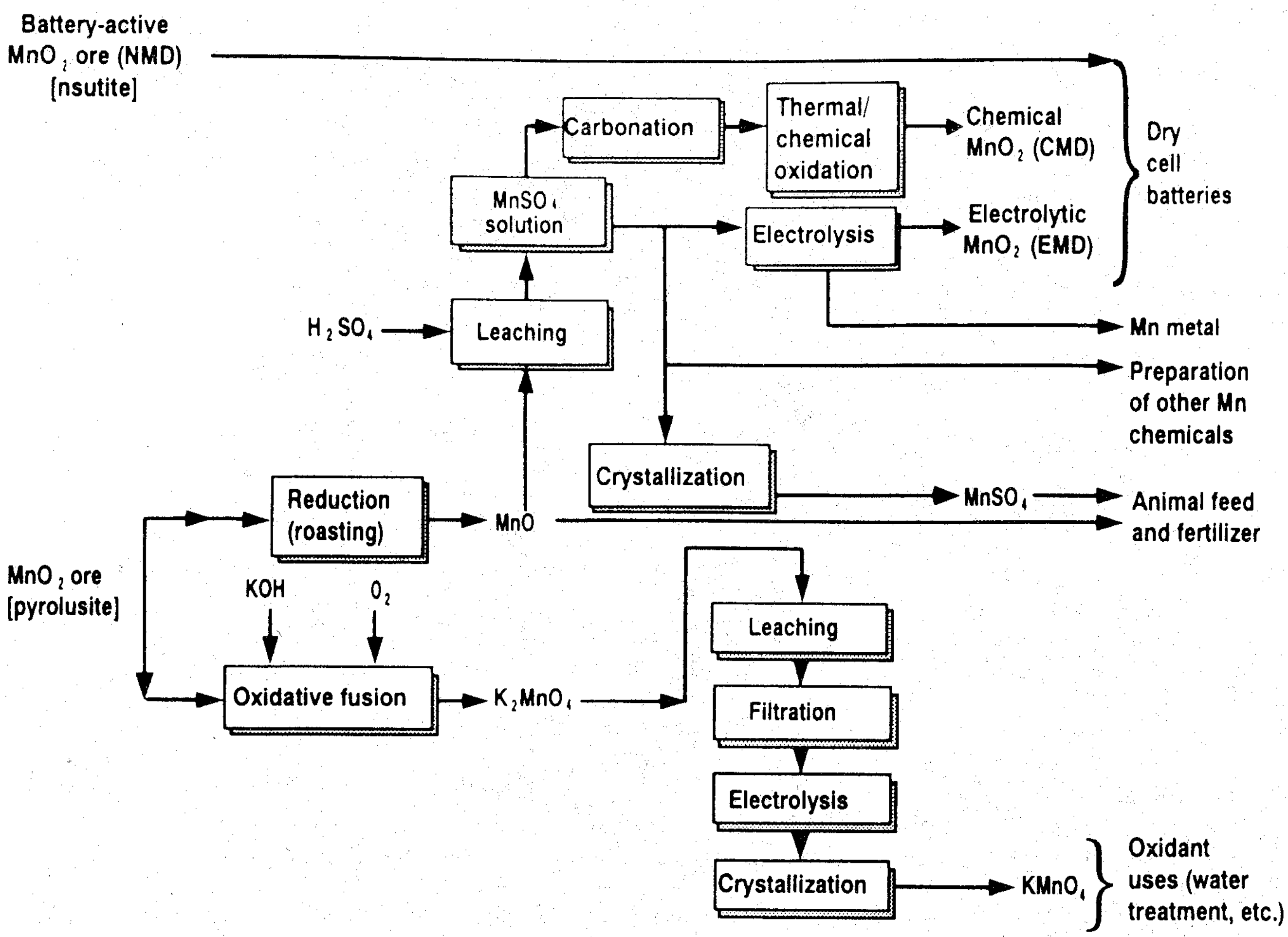


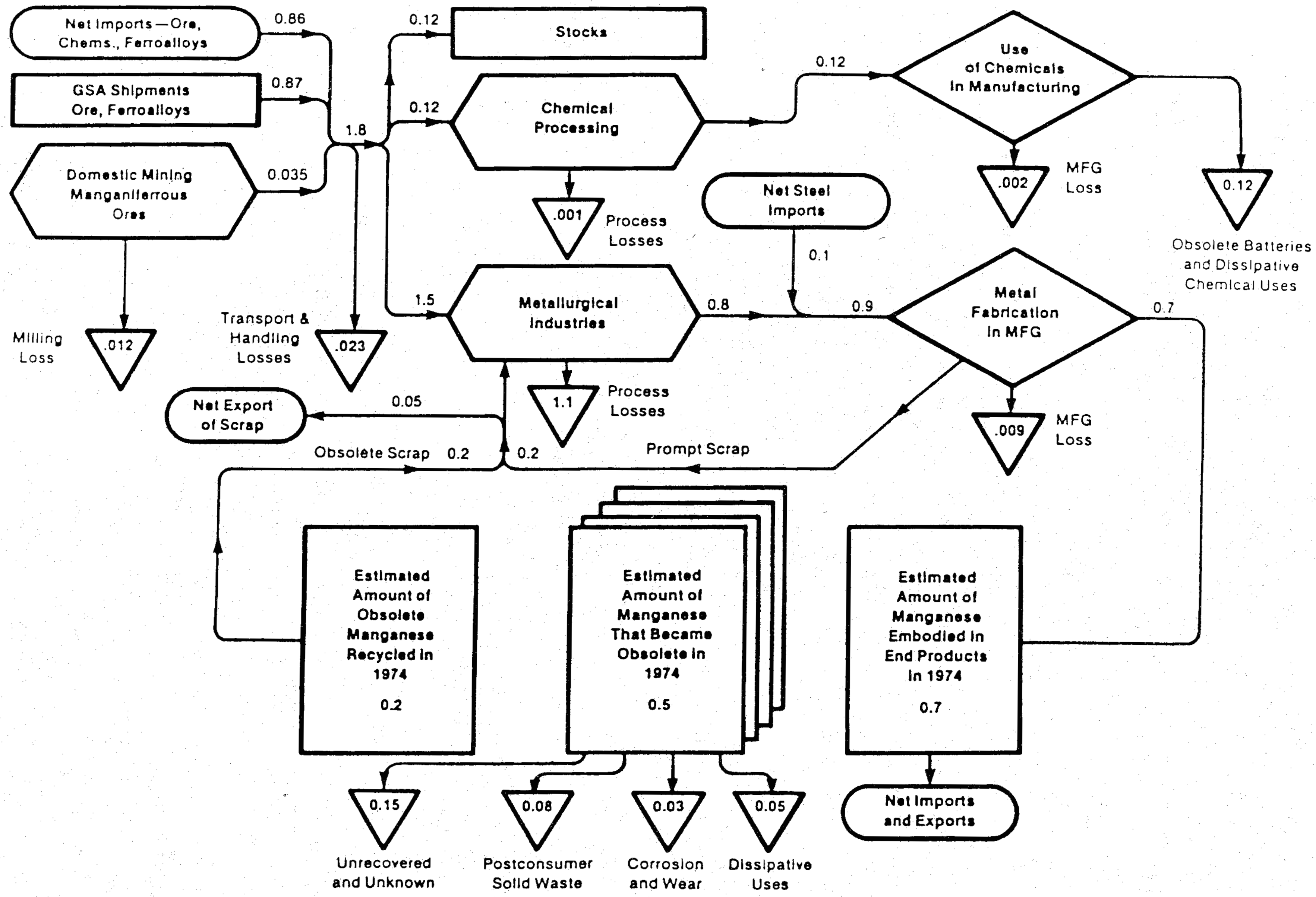
Figure 6.—Simplified diagram of processing and uses for key manganese chemicals.

(MnO) and manganese sulfate ($MnSO_4$) for use in animal feed and fertilizer, and potassium permanganate ($KMnO_4$) for various oxidative uses such as in water treatment. The Bureau estimated total manganese consumption in batteries in 1990 as 46,000 tons, or less than 7% of U.S. apparent consumption of manganese. The Bureau also estimated for 1990 that a total of 40,000 tons of manganese was consumed in the other nonmetallurgical uses of manganese. This included manganese used to darken or stain bricks in shades ranging from brown to gray to black. Sources of manganese included ground manganese ore and manganiferous schist mined in South Carolina that had a natural manganese content in the range of 5% to 15%.

MANGANESE FLOWS IN THE UNITED STATES

OVERALL ANNUAL MATERIAL CYCLE

In a report published in 1979, OTA presented material cycles in the 1974 U.S. economy for eight metals (*4*). The contractor that derived these cycles was Battelle Columbus Laboratories. The diagram for the manganese cycle is shown in figure 7, the construction of which utilized manganese data from the Bureau for mineral inputs, stock changes, and ore consumption. Relationships in the metallurgical industries portion of the diagram closely followed those in an analogous cycle constructed for iron and steel, in view of the strong association between manganese and the steel industry. Comparison of the manganese and the iron and steel cycles implies steel manganese contents in the range of 0.6% to 0.9%, depending on the particular item. Construction of the iron and steel cycle involved use of data on foreign trade for steel and steel scrap. It also entailed use of methodology developed by the contractor in making estimates of the amount of steel in service becoming obsolete and losses of obsolete steel.



Source: Reference 4, p. 35.

Figure 7.—Manganese cycle for 1974 in million short tons of manganese content.

According to this analysis, all of the 120,000 tons of manganese considered to have been consumed by the battery, chemical, and miscellaneous industries was used dissipatively and ended up being dispersed to the environment. This quantity corresponds to 8% of a U.S. apparent consumption of manganese in 1974 of 1,492,000 tons, as estimated by the Bureau.

The bulk of domestic manganese consumption was by the metallurgical industries, meaning the production and use of iron, steel, and manganese ferroalloys and metal. The total 1974 input of manganese to these industries was estimated as 1,850,000 tons, including a net of 350,000 tons from scrap recycle and export. The rate of loss in processing this input was estimated to have been about 60%. The processing loss of 1,100,000 tons thus estimated corresponds to 74% of the Bureau's estimate of apparent consumption. Nearly all of this loss was identified to be to slag from steelmaking.

The amount of manganese ending up in metal products was estimated as 700,000 tons, a figure whose estimation was dependent on estimation of the quantity of prompt (steel) scrap. The procedures used by the contractor in estimating the amount of prompt scrap were based on shipments data of the American Iron and Steel Institute (AISI) for 1974 plus use of prompt scrap generation factors developed at Fordham University by Father Hogan and associates.

The estimate of 500,000 tons as the amount of manganese in articles becoming obsolete was based on an estimate of the corresponding quantity for iron and steel. This was arrived at from estimates of the accumulated quantities of iron and steel contained in various products and their average useful lives. Weighted average product lives were estimated as 18 years for steel and 19 years for manganese. Estimated losses of manganese to postconsumer solid waste (76,000 tons), corrosion and wear (28,000 tons), and dissipative uses of obsolete articles (48,000 tons), which gave a rounded total of 160,000 tons, paralleled similar estimates made for iron and steel.

The estimate that 200,000 tons of manganese was recycled in obsolete articles also was based on a procedure used for making a similar estimate for the iron and steel cycle. Deducting this amount plus the 160,000 tons of specified losses from the 500,000 tons of manganese becoming obsolete gave a remainder of 140,000 tons (calculates to 148,000 in the relevant working paper and given as 150,000 in figure 7) that was labeled unrecovered and unknown.

Selected quantities from this manganese cycle for 1974 are listed in table 3, which also relates these quantities to the total manganese input to metallurgical industries, which was given an index value of 100. This table includes for comparison a set of figures for the same quantities for 1984 as obtained by an approximate update of the 1974 diagram.

Table 3.—Flows and losses in manganese material cycle, 1974 and 1984

Item	1974		1984[1]	
	Quantity		Quantity	
	Thousand short tons	Relative to input to metallurgical industries	Thousand short tons	Relative to input to metallurgical industries
Total manganese input to metallurgical industries	1,850	100	801	100
Process losses in metallurgical operations	1,100	59	(a) 400 (b) 320	(a) 50 (b) 40
Manganese embodied in end products	700	38	(a) 403 (b) 483	(a) 50 (b) 60
Losses as obsolete batteries and through dissipative chemical use	120	6	89	11
Losses as obsolete articles:				
Dissipative uses	50	3	33	4
Corrosion and wear	30	2	34	4
Postconsumer solid waste	80	4	68	8
Unrecovered and unknown	150	8	130	16
Total	310	17	265	33

[1](a) Denotes an assumed processing loss of 50% and (b) a loss of 40%.

In making the 1984 update, it was considered beyond the scope of this study to follow in detail the procedures employed by the contractor in achieving the 1974 cycle. For expediency and other considerations, the procedures used differed in several respects from those on which the 1974 diagram is based:

1. The metallurgical industries processing loss was arbitrarily assumed to decrease to 50% (case "a") in line with the trend projected in the later OTA study published in 1985 (*2*). In conjunction with other assumptions, this produced a product manganese content of about 0.5%, which seemed low. Consequently, another calculation was made in which the processing loss was decreased to 40% (case "b"), which produced a product manganese content of about 0.6%.

2. Quantities of prompt scrap generated and of obsolete scrap recovered were obtained from the "1984 Flow of Iron Units in the United States" diagram prepared by the Charge Materials Committee of the American Foundrymen's Society (*5*). This committee had issued this type of diagram annually for a number of years, but ceased doing so as of the diagram for 1984. The choice of 1984 for updating the 1974 manganese materials cycle was predicated upon the availability of this diagram.

3. The quantity of iron and steel becoming obsolete in 1984 was determined by extrapolation from data developed by R. R. Nathan Associates (RRNA) (*6*).

4. On a judgmental basis, average product lives were increased somewhat, in the case of manganese to 22.5 years. This was done as a compromise with an average life of 25 years that OTA noted was indicated to have been used in a 1977 study of steel scrap by RRNA.

5. In estimating losses from articles becoming obsolete, the loss rate for corrosion and wear was increased to 0.36% from 0.34%, as suggested in an updated study of steel scrap by RRNA (*7*). Losses otherwise from obsolete articles were assumed to be in the same proportions as in 1974.

For the 1974 and 1984 material cycles, one of the essential points indicated in table 3 is that the predominant loss of manganese occurs during processing in metallurgical operations, specifically into steel slag as already mentioned. For 1974, it was noted that three-fourths of the manganese used annually was estimated to have been lost and that two-thirds of this loss was associated with steelmaking. The rate of this loss is presumed to have decreased by as much as one-third between 1974 and 1984. Considering collectively battery and chemical applications of manganese and articles becoming obsolete, another indication is that the order of magnitude of losses other than in metallurgical operations did not change substantially and, if anything, may have decreased. Comparing 1984 with 1974, the decrease of more than 50% in the quantity of manganese input to metallurgical operations occurred because of the sharp decline of nearly 40% in raw steel production combined with an increase in the efficiency of manganese use by the steel industry. This had the effect of increasing the relative proportion of eventual loss of manganese as batteries, chemicals, and obsolete articles.

STEELMAKING

Analyses of manganese flows in the blast furnace-basic oxygen furnace (BF-BOF) sequence employed by integrated steel producers were published during 1976-85 by NMAB (*1*), the International Iron and Steel Institute (IISI) (*8*), and OTA (*2*). For this steelmaking sequence, iron ore is mined and smelted to pig iron from which carbon is removed in an oxygen converter prior to alloying and final composition adjustment.

The three analyses are discussed in more detail in appendix A. The respective manganese balances are presented in table 4 and as a composite diagram in figure 8. The difference of about 10% between the totals in the table and those for the numerical averages in the figure result from different ways of including data for slag recycling. The essential point is that the processing losses are indicated to be in the range of about 12 to 16 pounds of manganese per ton of raw steel. For the IISI study, the value depends on whether imbalances in the subdiagrams for the blast furnace and the oxygen converter are included. OTA indicated an additional small loss in casting/finishing. The nature of this loss is not described, but could be assumed to be such as oxide scale, grinding dusts, and other wastes normally resulting from the shaping and conditioning of steel, a good deal of which typically ends up being recycled to steelmaking or put to other uses.

OTA does not emphasize, as do IISI and NMAB, that nearly all the manganese loss is as a component of various slags, most likely as manganous oxide, MnO. Flue dust is the only other form of loss identified by IISI, which assigns 99% of losses to slag. NMAB identifies losses as only to slag. Manganese contents are typically less than 1% in blast furnace slag (*9*) and in the range of 3% to 7% in BOF converter slag (*1*, p. 21) and teeming ladle slag (*10*).

Manganese losses to slag in 1990 can be estimated to have been at least 352,000 tons, or about one-half of a U.S. manganese apparent consumption of 695,000 tons, assuming the average manganese content of blast furnace slag to have been 0.3% and that of steel slag 4.0%. These average slag manganese contents were inferred from information in various published and unpublished sources. Actual quantities of slag produced are not known, so that Bureau figures for slag sold or used were taken to represent at least minimum quantities produced. These were 16,597,000 tons for blast furnace slag and 7,552,000 tons for steel slag (*11*). An allocation of pounds of manganese lost to slag per ton of raw steel produced can be made by relating these quantities to a raw steel production of 98.9 million tons. Estimated this way, the slag manganese loss was 7.1 pounds per ton of raw steel, of which 1.0 pound was in blast furnace slag and 6.1 pounds was in steel slag. The estimated total loss is in the vicinity of roughly 50% of those already discussed in the three analyses of integrated steelmaking.

In 1990, about 60% of domestic steel production was by the BF-BOF route depicted. All other production took place in scrap-based electric arc furnaces (EAF's) with the exception of a small quantity of steel produced in open-hearth furnaces. By the end of 1991, open-hearth furnace production had ceased. A manganese flow diagram similar to those for integrated steelmaking seemingly has not been developed for EAF steelmaking. Compared to BOF steelmaking, EAF steelmaking tends to retain more manganese and make products with generally higher carbon contents.

Table 4.—Manganese balances for integrated steel production

(Pounds of manganese per ton of raw steel)

	OTA	IISI	NMAB
		INPUTS	
Iron ore, etc.	9.65	8.86	[1]7.70
Manganese ore	1.42	3.06	([2])
Purchased scrap	3.73	4.16	4.10
Mn ferroalloys	11.92	9.60	12.00
Home scrap from casting/finishing	3.11	—	—
BOF slag	([2])	4.20	6.50
Total	29.83	29.88	30.30
		OUTPUTS, GROSS	
BF slag/dust	2.77	2.84	2.10
BOF slag/dust	11.11	[3]12.78	[4]16.20
Ladle waste/slag	2.14	1.00	—
BF imbalance	—	1.80	—
BOF imbalance	—	1.26	—
Total nonsteel	16.02	19.68	18.30
Raw steel	13.80	10.20	12.00
Grand total	29.82	29.88	30.30
		PROCESSING LOSSES	
BF slag/dust	2.77	2.84	2.10
BOF slag/dust	11.11	8.58	9.70
Ladle waste/slag	2.14	1.00	—
Total	16.02	12.42	11.80
Additions for imbalances, IISI:			
BF imbalance	—	1.80	—
BOF imbalance	—	1.26	—
Adjusted total	16.02	15.48	11.80

[1]Includes manganese ore.
[2]Included with iron ore.
[3]8.44 not recycled.
[4]9.70 not recycled.

NOTE.—Dashes indicate zeros.

Source: Based on data of OTA (reference 2, 1985), IISI (reference 8, 1980), and NMAB (reference 1, 1976).

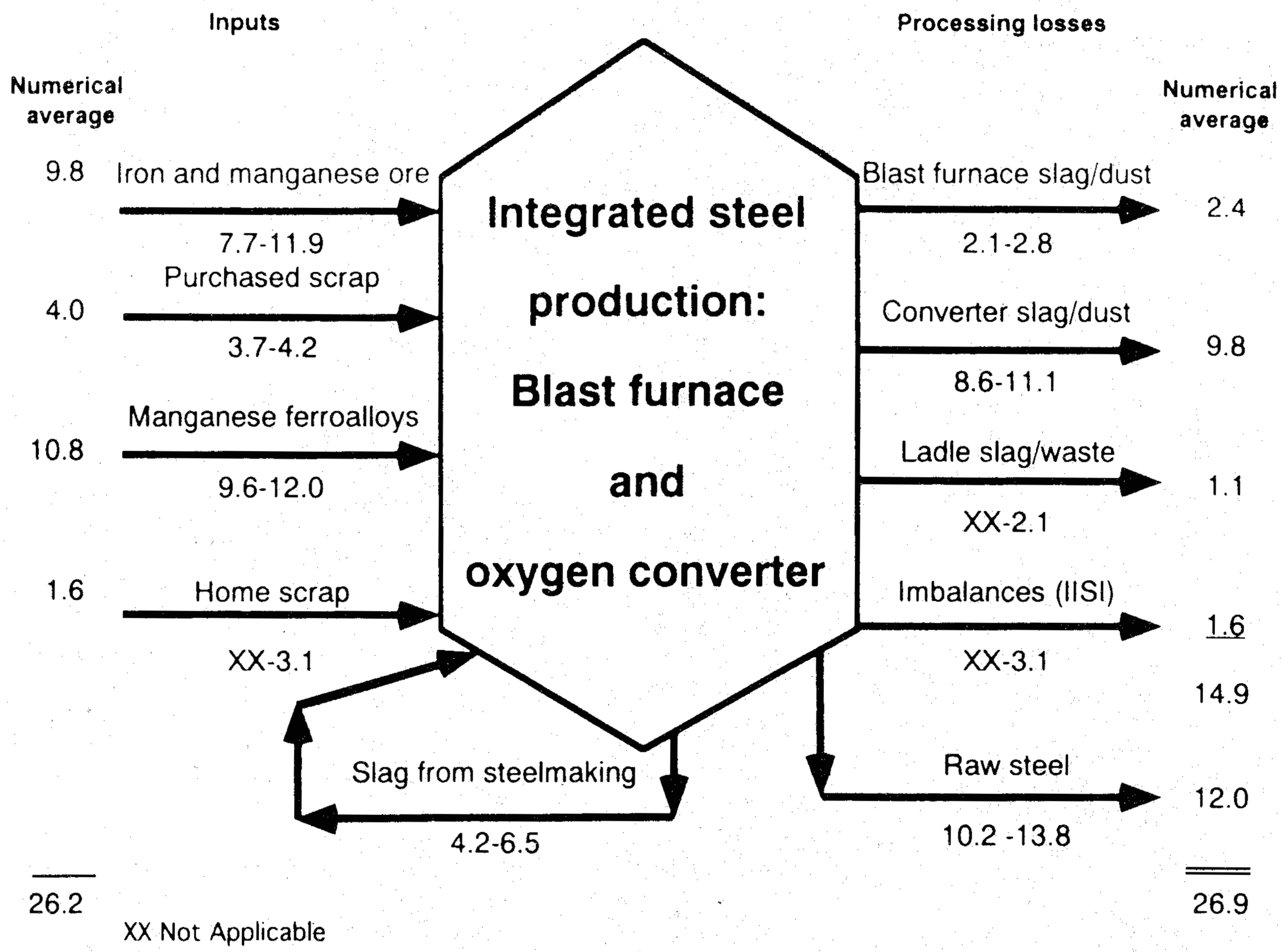


Figure 8.—Composite of manganese balances for integrated steel production in pounds of manganese per ton of raw steel. Based on data of OTA (reference 2, 1985), IISI (reference 8, 1980), and NMAB (reference 1, 1976).

Information from one EAF producer indicates that the main features of an overall manganese balance for their operations would not differ drastically from those representing BF-BOF steelmaking: (1) Total manganese input/output is quite comparable, (2) input of manganese units is about equally divided between scrap and ferroalloy (silicomanganese), and (3) loss of manganese to slag is comparable, possibly slightly less (*12*). This EAF operation is accompanied by a loss of manganese from the furnace in dust in an amount corresponding to about 6% of the manganese units contained in the scrap charge. It would be anticipated that almost all of this dust, which for this particular plant had an average manganese content of about 2%, would be captured in the pollution control systems of the melt shop.

MANGANESE FERROALLOYS AND METAL

The nature of operations in 1990 at the two domestic plants will be discussed only qualitatively to avoid disclosing proprietary data, production, and capacities. Additional information relevant to these operations can be found in appendix A.

Processing of manganese ore into ferroalloys by Elkem Metals was by what is commonly referred to as an integrated scheme whereby slag from the production of ferromanganese constituted part of the feed to silicomanganese production. The nature of this scheme and the associated complex and interrelated material flows are illustrated in figure 9, in which one portion depicts operations at Japan Metals and Chemicals Co. (JMC) in the 1970's and another at Elkem Metals' sister plant at Sauda, Norway, in the 1980's. Both at Sauda and Marietta, production of high-carbon ferromanganese and silicomanganese was accomplished in electric furnaces and medium-carbon ferromanganese was produced by refining liquid high-carbon ferromanganese in an oxygen converter ("MOR process").

In 1990, Elkem Metals was engaged at Marietta in conversion of manganese ore from the National Defense Stockpile into high-carbon ferromanganese. In that year, about 56,000 tons of ferromanganese was accepted into stockpile inventory, although the annual level of such conversions was more typically around 70,000 tons of product. Besides high-carbon ferromanganese, Elkem Metals additionally produced medium-carbon ferromanganese and silicomanganese. Any ore used other than that from the stockpile was from foreign sources. Typically, the tons of ore used would have been about twice the tons of ferroalloys produced. The output of the plant can be considered to consist of ferroalloys suitable for use in steelmaking, fine particles of ferroalloys referred to simply as fines, slag, and dust.

In a plant of this type, overall recovery of manganese in ferroalloys can be taken as about 85%. In single furnace plants, the recovery would be lower at about 75%. A high percentage of the manganese ferroalloys produced is consumed in steelmaking. Relatively small quantities are consumed in iron foundries and such other activities as manufacture of welding fluxes and rods. Fines are reprocessed by charging them back into the electric smelting furnaces, by making them into briquettes for uses similar to those for lump material, and by selling them for a variety of uses, such as manufacture of fluxes and manganese-bearing materials used in agriculture.

In producing manganese metal, Elkem Metals and Kerr-McGee used an electrolytic process for extracting manganese. Annual capacities in 1990 of the two domestic metal plants have been given as about 12,000 tons for Kerr-McGee and 11,000 tons for Elkem Metals (*13*, p. 37). Starting with either ferromanganese slag at Elkem Metals or with (imported) ore at Kerr-McGee, a manganese-bearing solution is produced by a sulfuric acid leach. After various purification steps, this solution is electrolyzed to plate out manganese on a cathode from which it is removed as thin flakes. Final products are obtained by washing the flakes or by grinding them into powder. As of the 1960's, overall yields were in the vicinity of 80% (*14*) and presumably have been improved since. Processing wastes consist of such items as leaching residues, filter cakes from purification, and solutions that go to settling ponds.

The largest application of manganese metal is in aluminum alloying, particularly the alloys from which items such as beverage cans and siding are made. In modern technology, the predominant form in which manganese is added to molten aluminum is as a briquette (typically 75% manganese, 25% aluminum) made by compacting powders of the two metals. In 1990, the amount of manganese metal used by the steel industry was about one-third as much as by the aluminum industry, as indicated in table 2. Because use of manganese metal, as opposed to a ferroalloy, is a relatively expensive way of adding manganese, the metal is added in steelmaking as a "trimming addition" to adjust final composition, particularly when an increase in carbon content is not permissible.

Manganese added to steel as metal becomes indistinguishable from manganese added using ferroalloys, and, in either case, the chemistry associated with the steelmaking cycle is such that the manganese addition made during a previous cycle can be thought of as lost during the next cycle. By contrast, manganese alloyed with aluminum accumulates upon aluminum recycling, as with beverage cans, so that it may become necessary to add aluminum rather than manganese to achieve the desired final composition.

Other, relatively minor uses of manganese metal are in alloying with other nonferrous metals, principally copper; as feed material for chemicals manufacture; and manufacture of welding rods and fluxes.

NONMETALLURGICAL APPLICATIONS

Quantitative estimates of the amount of manganese associated with flows during stages in the various nonmetallurgical uses of manganese cannot be given because in each case doing so could reveal proprietary data pertaining to the limited number of companies involved.

Dry Cell Batteries

Stages in the domestic manufacture and usage of dry cell batteries containing manganese dioxide occurring naturally (NMD) and/or synthetic dioxide prepared electrolytically (EMD) or chemically (CMD) are sketched in figure 10. EMD was the only one of these forms of dioxide that was produced domestically for use in batteries in 1990. EMD producers in that year, with a combined annual capacity of about 40,000 tons, were Chemetals Inc. at New Johnsonville, TN; Kerr-McGee Chemical Corp. at

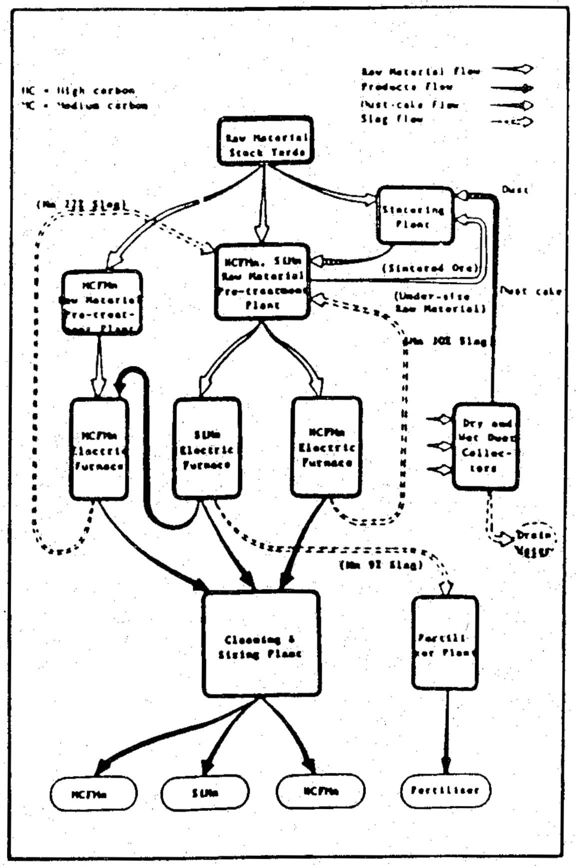


Figure 1
Interrelation between individual production units

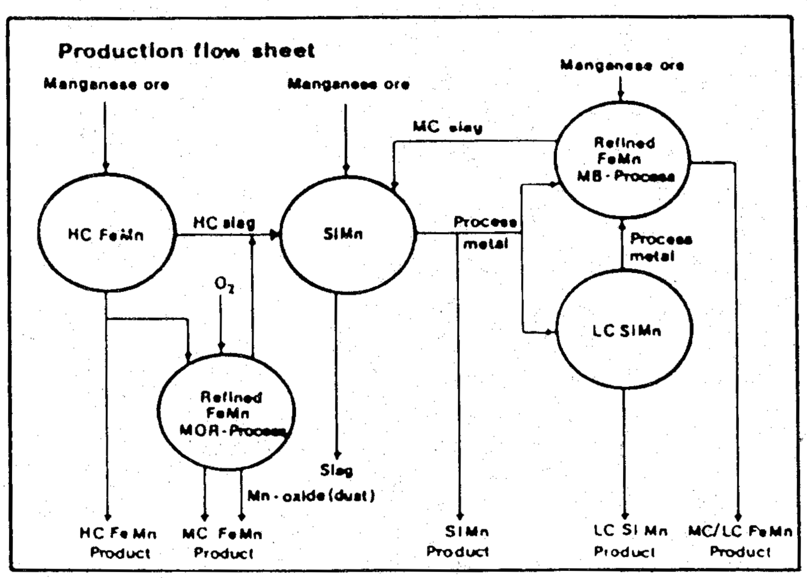


Fig. 1. Production flow sheet for products at Sauda Smelteverk.

Figure 9.—Materials flow in integrated production of manganese ferroalloys. Upper diagram: Japan Metals and Chemicals Co. (Source: T. Tomioka, M. Misawa, and T. Hanano. An Integrated Production System for Manganese Ferroalloys. INFACON 74. Johannesburg, The South African Institute of Mining and Metallurgy 1974, p. 129); lower diagram: Elkem A/S (Source: Min. Mag., v. 156, No. 6, June 1987, p. 491).

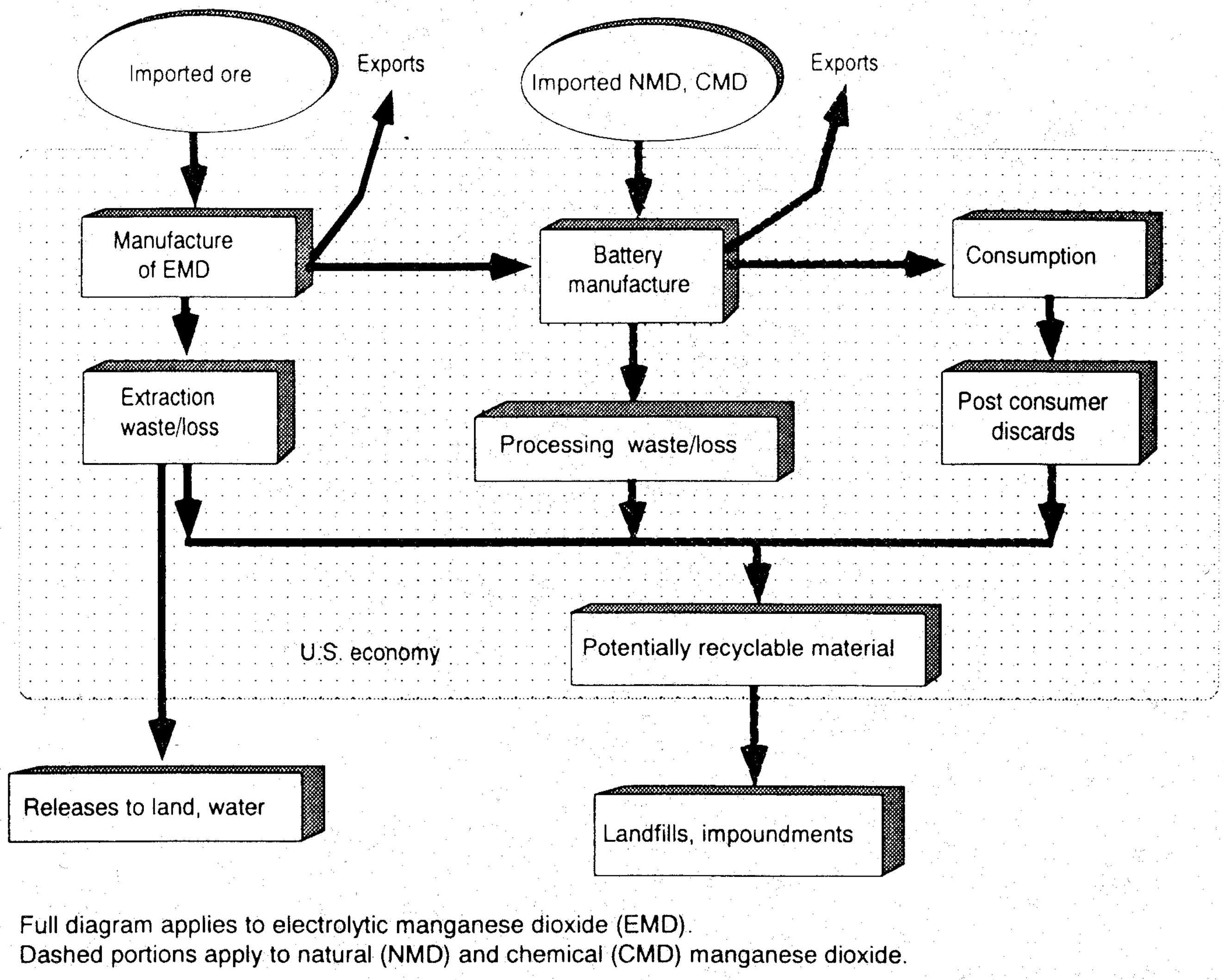


Figure 10.—Flow diagram for manganese use in dry cell batteries.

Henderson, NV; Eveready Battery Co. at Marietta, OH; and Rayovac Corp. at Covington, TN. EMD imports in 1990 were about 7,700 tons. The sequence of steps for processing manganese ore into EMD and physical form of the product are much the same as for manganese metal.

The other forms of dioxide for battery use were imported in 1990. CMD, including any for battery use, has been imported regularly from the manganese chemicals plant of Sedema SA, sister company to Chemetals, in Belgium. During the 1980's, the annual level of these imports averaged about 1,100 tons within a range of about 400 to 2,000 tons. Chemetals had a facility at Baltimore, MD, with an annual capacity of about 6,000 tons for CMD, but the dioxide produced was for nonbattery applications. Battery-active NMD of domestic origin has not been shipped domestically since 1968. Because the tariff system distinguishes manganese ore only on the basis of its manganese content, the level of NMD imports cannot be determined but is believed to be small. Export quantities for the three forms of dioxide cannot be stated with any precision.

In 1990, practically all domestic manufacturing of manganese batteries was by three companies: Duracell Inc., Eveready, and Rayovac. Duracell made only the alkaline type of battery, which requires EMD as active agent, as opposed to carbon-zinc batteries, which employ NMD in the battery mix and are declining in consumer preference. Data from investigations by the U.S. International Trade Commission in the 1980's into charges of dumping of EMD in the United States indicated U.S. apparent consumption of EMD was, in tons, 41,500 in 1985, 45,500 in 1986, 44,300 in 1987, and 47,300 in 1988 (*15*). In terms of manganese content, these quantities would convert to an average of about 27,000 tons.

Ignoring net foreign trade, the ultimate destination of manganese batteries is to waste disposal at the end of a life after manufacturing averaging about 2 years (*16*). In 1990, at best only a few local programs existed whereby manganese-containing batteries were recycled. The main impetus for recycling household batteries was their mercury content, although, as of 1990, for batteries based on NMD, this content had been reduced to zero and had been lowered to 0.025% for alkaline batteries, with the prospect of also being reduced to zero within a few years. Manganese yields in battery manufacture are not known; wastes consist of scrapped or rejected MnO_2-bearing mix. Wastes from EMD manufacture are similar to those from the production of metal; i.e, leaching residues, filter cakes, and solutions going to settling ponds.

Brick Coloring

The amount of manganese used for this purpose in 1990 is estimated to have been only a few percent of U.S. apparent consumption. In general, ground ore would have been of foreign origin, although, as indicated in figure 11, ore for brick coloring was being obtained from Government stockpiles, some of which may have been of domestic origin. Ore from Morocco (Imini Mine) has traditionally been a preferred material for brick coloring.

The manganese addition to brick can be either a surface or a body addition. Spraying is one of the methods used to color just the surface and tends to be the practice for bricks used in residential construction. For bricks used in commercial construction, the tendency is to add manganese to the mix being extruded into shapes in order to achieve coloring throughout the body. Once the brick has been fired, the addition is essentially permanent, although some can be leached ("staining") if improper methods are used to clean the brick, as with hydrochloric acid.

Release of manganese to the environment from the making and use of brick is believed to be insignificant. Losses at the mine site are localized and become a component of backfilling and reclamation. A low percentage of

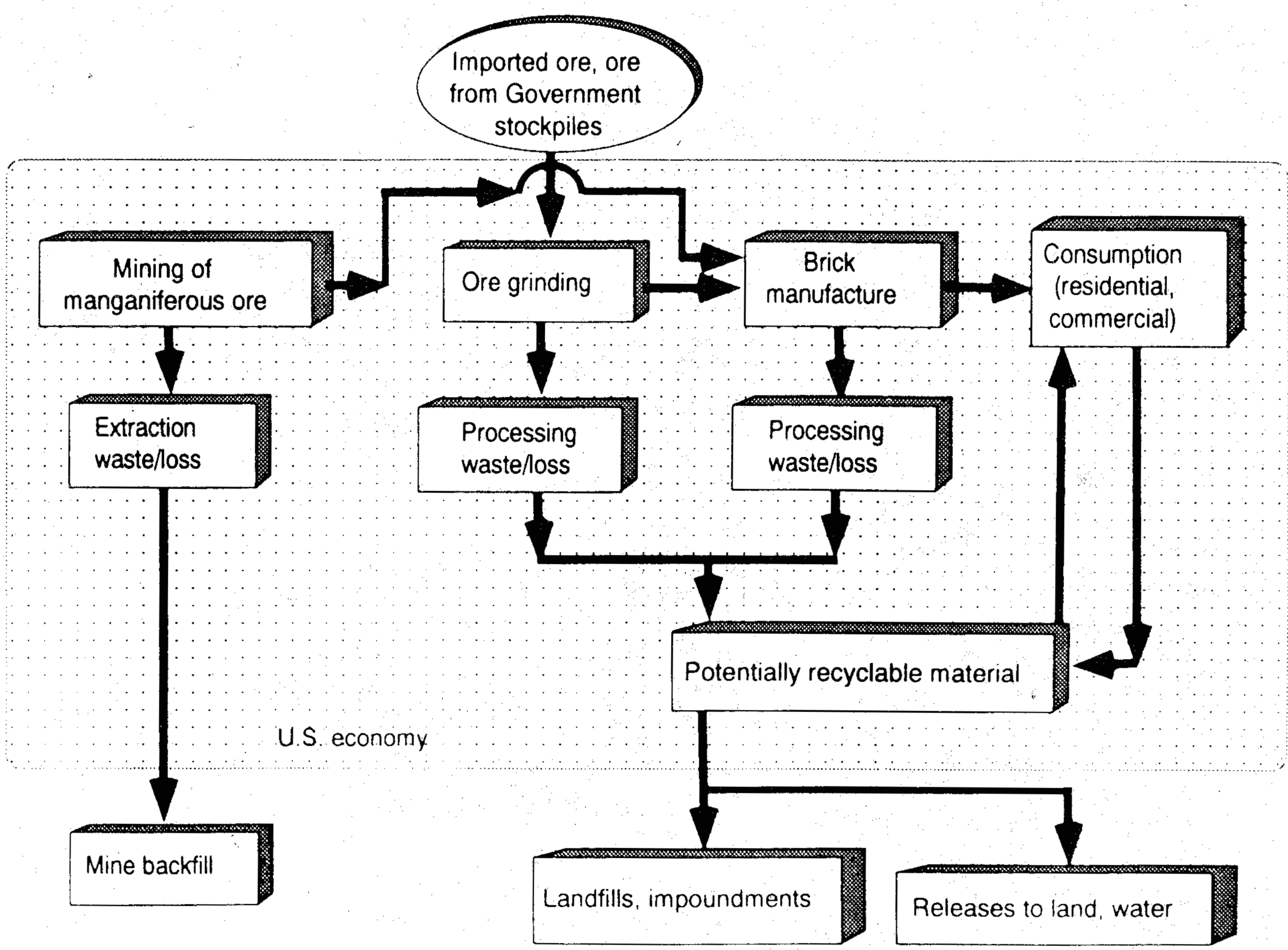


Figure 11.—Flow diagram for manganese use in brick coloring.

the total brick used is recycled as "used brick" for building purposes. Otherwise, wastes from brickmaking and building construction and demolition go to landfill as inert material. The "life" of a brick typically is indefinite, essentially determined by the life of the building in which it is used.

Animal Feed and Plant Fertilizer

Manganese is used in animal feed to supply an essential element and to fertilize plants to avoid or correct the effects of soil deficiencies. The quantity of manganese used for these purposes domestically in 1990 is estimated to have been about the same as for brick coloring; i.e, only a few percent of apparent consumption.

The basic forms of manganese used were manganous oxide (MnO), manganese sulfate ($MnSO_4$), and manganese oxysulfates that were either physical or chemical combinations of MnO and $MnSO_4$. These materials are solids, except that the sulfate was available as a dilute solution that was a byproduct of ferroalloy operations. As indicated in figure 12, the manganese units for these materials were ultimately obtained from foreign countries as manganese ore or manganese sulfate. Ore was ground and roasted to produce MnO that was used in that form or to manufacture the sulfate and oxysulfate. Alternatively, manganese units to make the sulfate and oxysulfate could be obtained from ferroalloy fines and dusts. Manganese sulfate had been predominantly an item of domestic manufacture until Tennessee Eastman Co. ceased in 1986 to produce it at Kingsport, TN, as a byproduct from manufacture of hydroquinone.

Agricultural use of manganese can be considered as totally dissipative. Chief applications in animal feed are for poultry and livestock. Common uses in fertilizer, directly or as a micronutrient, are in the growing of citrus plants and soybeans. The main areas of fertilizer use in the United States are the South Atlantic and East North Central States.

Permanganates and Other Chemicals

Domestic consumption of manganese for production of manganese chemicals other than those already discussed

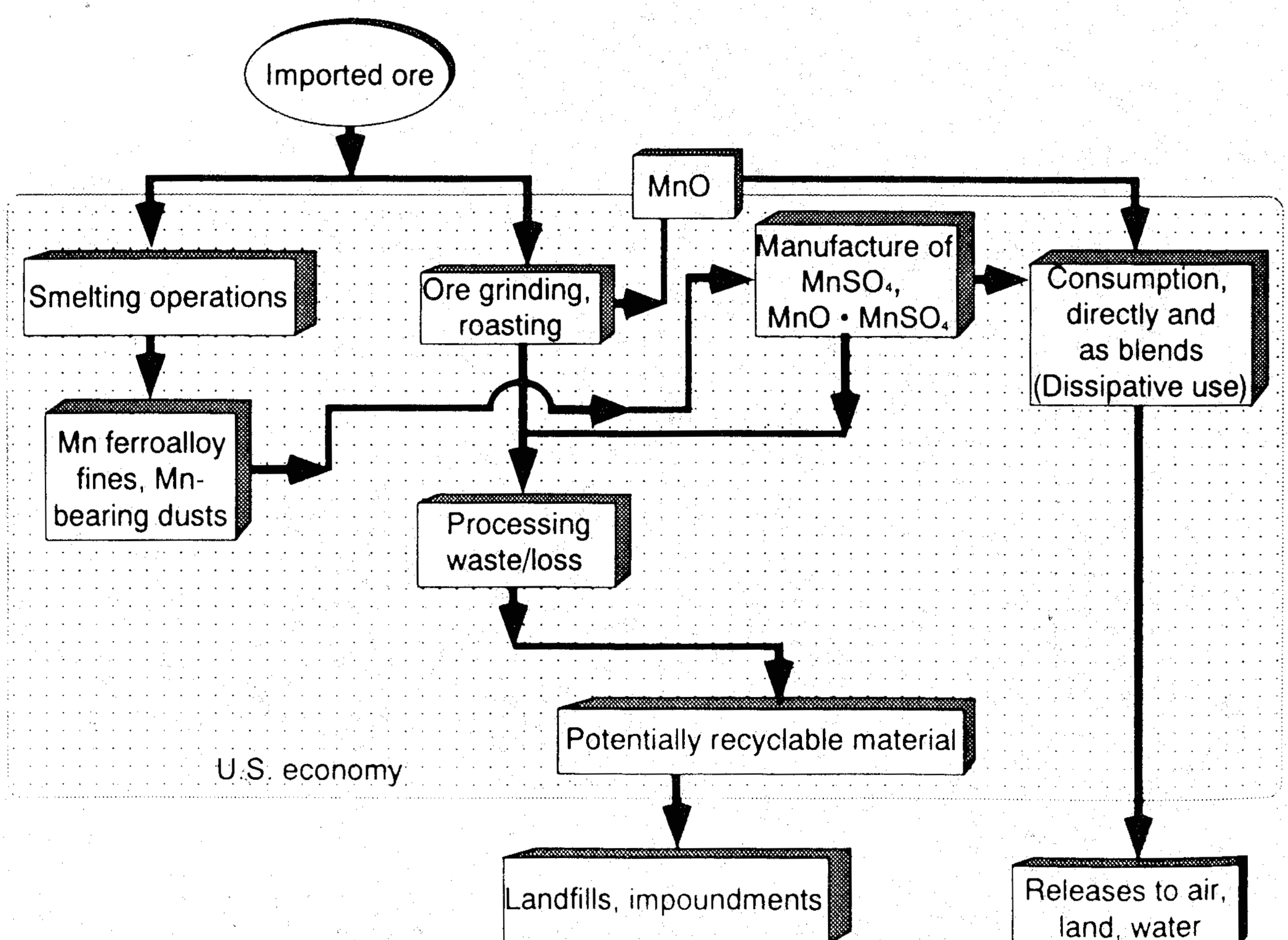


Figure 12.—Flow diagram for manganese use in animal feed and plant fertilizer.

is estimated to be less than that for either brick coloring or agricultural uses. Potassium permanganate is possibly the most economically significant of these other manganese chemicals. The flowchart for its manufacture has already been given in figure 6. The only domestic producer of the permanganate is Carus Chemical Co., La Salle, IL, whose annual capacity as of 1990 was about 16,000 tons (*17*). While Carus has been the dominant supplier to the U.S. economy, imports, particularly those from China and Spain, have concerned Carus sufficiently in the 1980's to cause Carus to seek tariff relief from the Federal Government (*18*).

The variety of manganese chemicals produced and their uses includes manganese borate used as varnish dryer, manganese citrate and hypophosphite used as dietary supplements, manganese phosphate used to rustproof iron and steel surfaces, and manganese salts of organic acids (such as manganese resinate) used in leather tanning and as a mordant in dyeing (*19*). Information about these and such other diverse uses of manganese as fungicide and as catalyst in organic reactions are given in a 1977 book (*20*). These uses are all considered to be dissipative. The main forms in which manganese is released to the environment during chemicals manufacture appear to be as unreacted ore and dilute concentrations of salts in effluent from waste treatment plants.

CUMULATIVE

The Bureau has been calculating U.S. annual apparent consumption of manganese for many years by means of the basic relation whereby apparent consumption is equated to domestic mine production plus shipments of Government stockpile excesses plus imports minus exports plus the net change in industry and Government stocks. This has been done on the common basis of manganese content, either actual or as estimated depending on the data available. The results for 1980-90 are shown in table 5, which includes the estimated distribution of consumption among principal categories of end uses. In this and other similar tables for manganese published by the Bureau, apparent consumption is synonymous with either "Industrial demand" or "Total U.S. primary demand" because recycling explicitly for manganese has been insignificant.

Table 5.—U.S. manganese supply-demand relationships, 1980-90[1]

(Thousand short tons, manganese content)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
	COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Domestic mines[2]	23	24	4	4	11	2	1	2	1	1	1
Shipments of Government stockpile excesses	159	128	28	35	10	91	8	105	-2	-6	22
Imports, ore and dioxide[1]	330	301	111	178	180	204	237	181	262	303	169
Imports, ferroalloy and metal	530	615	430	364	426	405	452	422	581	553	505
Industry stocks, Jan. 1	749	710	702	576	463	420	380	315	279	316	324
Total U.S. supply	1,791	1,778	1,275	1,157	1,090	1,122	1,078	1,025	1,121	1,167	1,021
Distribution of U.S. supply:											
Industry stocks, Dec. 31	710	702	576	462	420	380	315	279	316	324	266
Exports, ore	26	32	14	10	30	31	23	38	35	29	46
Exports, ferroalloy and metal	26	17	13	17	13	13	10	9	18	17	14
Industrial demand	1,029	1,027	672	668	627	698	730	699	752	797	695
	U.S. DEMAND PATTERN[3]										
Appliances and equipment	49	51	30	33	36	32	27	31	19	12	10
Batteries	17	16	21	25	34	39	43	43	48	45	46
Cans and containers	49	46	31	28	38	35	31	35	31	23	24
Chemicals[4]	50	50	29	22	34	22	23	44	46	43	40
Construction	243	252	152	151	170	164	148	165	244	152	152
Machinery	167	171	92	90	97	78	65	77	110	83	82
Oil and gas industries	79	89	40	28	36	34	25	30	21	10	15
Transportation	214	214	115	129	139	124	95	105	102	54	50
Other[5]	161	138	162	162	43	170	273	169	131	375	276
Total U.S. primary demand	1,029	1,027	672	668	627	698	730	699	752	797	695

[1]Where available, data for manganese dioxide included beginning in 1984.
[2]Including manganiferous ore.
[3]New series for steel-related end uses beginning in 1989.
[4]Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.
[5]Not specifically based on reported data; includes processing losses. Through 1988, the distribution within this category is approximately the same as for end uses above. Beginning in 1989, includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

Source: U.S. Bureau of Mines Commodity Annual Report for Manganese, 1991.

The results of apparent consumption calculations for 1960-90 are given in table 6 for only the components and distribution of supply, along with totals for this 31-year period. The summation indicates that a manganese apparent consumption of 33,544,000 st during this time interval was achieved by, in units of thousand short tons, net imports (imports minus exports), 29,027; shipments of Government stockpile excesses, 2,090; domestic mines, 1,245; and decrease in industry stocks, 1,182 (1,448 - 266). The percentages of the total were 86, 6, 4, and 4, respectively.

Because of the high dependence of manganese demand on steel production, it is to be expected that trends in U.S. apparent consumption (AC) would have a close relationship to trends in raw steel production (RSP). Data for these quantities in 1901-90 are listed in table 7. The apparent consumption data in this table for 1951-90 either have been published previously (1960-90) or have been obtained using the same type of data (1951-59). Those for 1901-50 are from an internal Bureau tabulation whose bases of calculation may not have been precisely the same as those for 1951 and later. The table contains a column for the ratio of apparent manganese consumption to raw steel production (AC/RSP). Because of the possibility that this ratio could itself be dependent on the level of steel production, this table includes an additional column giving the ratio between the AC/RSP ratio and raw steel production; i.e., $AC/(RSP)^2$.

Table 6.—U.S. manganese supply and apparent consumption, 1960-90[1]

(Thousand short tons, manganese content)

Year	Inputs						Outputs			Apparent consumption
	Industry stocks, Jan. 1	Domestic mines[2]	Shipments of Government stockpile excesses	Imports		Total supply	Exports		Industry stocks, Dec. 31	
				Ore and dioxide[1]	Ferroalloy and metal		Ore	Ferroalloy and metal		
1960	1,448	117	-353	1,215	103	2,530	3	3	1,447	1,077
1961	1,447	78	-570	988	184	2,127	4	3	1,278	842
1962	1,278	73	-328	933	145	2,101	4	5	1,114	978
1963	1,114	94	-188	993	132	2,145	4	2	1,043	1,096
1964	1,043	79	-99	984	170	2,177	7	6	948	1,216
1965	948	83	-101	1,221	211	2,362	7	5	977	1,373
1966	977	88	-53	1,223	221	2,456	8	2	1,093	1,353
1967	1,093	73	52	978	193	2,389	8	3	1,171	1,207
1968	1,171	48	73	870	183	2,345	10	5	1,180	1,150
1969	1,180	93	50	992	257	2,572	10	4	1,241	1,317
1970	1,241	66	140	847	238	2,532	10	20	1,175	1,327
1971	1,175	38	118	938	212	2,481	25	5	1,281	1,170
1972	1,281	29	218	793	305	2,626	12	7	1,241	1,366
1973	1,241	31	242	722	336	2,572	29	11	978	1,554
1974	978	35	807	593	376	2,789	107	7	1,183	1,492
1975	1,183	19	309	766	346	2,623	125	6	1,359	1,133
1976	1,359	31	294	649	478	2,811	64	10	1,373	1,364
1977	1,373	27	358	454	481	2,693	69	9	1,092	1,523
1978	1,092	38	279	278	604	2,291	100	17	811	1,363
1979	811	31	264	244	708	2,058	29	30	749	1,250
1980	749	23	159	330	530	1,791	26	26	710	1,029
1981	710	24	128	301	615	1,778	32	17	702	1,027
1982	702	4	28	111	430	1,275	14	13	576	672
1983	576	4	35	178	364	1,157	10	17	462	668
1984	463	11	10	180	426	1,090	30	13	420	627
1985	420	2	91	204	405	1,122	31	13	380	698
1986	380	1	8	237	452	1,078	23	10	315	730
1987	315	2	105	181	422	1,025	38	9	279	699
1988	279	1	-2	262	581	1,121	35	18	316	752
1989	316	1	-6	303	553	1,167	29	17	324	797
1990	324	1	22	169	505	1,021	46	14	266	695
Summation	1,448	1,245	2,090	19,137	11,166	35,086	949	327	266	33,544

[1]Where available, data for manganese dioxide included beginning in 1984.

[2]Including manganiferous ore.

Table 7.—Relationships between manganese apparent consumption (AC) and raw steel production (RSP), 1901-90

Year	AC (thousand short tons)	RSP (million short tons)	10^3 × ratio of AC/RSP	10^9 × ratio of AC/(RSP)^2
1901	115	14.78	7.78	0.526
1902	174	16.40	10.61	.647
1903	191	15.87	12.04	.758
1904	110	15.21	7.23	.475
1905	196	21.88	8.96	.409
1906	230	25.44	9.04	.355
1907	259	25.38	10.20	.402
1908	213	15.38	13.85	.900
1909	193	26.22	7.36	.281
1910	282	28.33	9.95	.351
1911	248	25.94	9.56	.369
1912	211	34.08	6.19	.182
1913	372	34.09	10.91	.320
1914	288	25.61	11.25	.439
1915	261	35.18	7.42	.211
1916	530	46.79	11.33	.242
1917	727	49.79	14.60	.293
1918	789	49.01	16.10	.328
1919	485	38.10	12.73	.334
1920	608	46.18	13.17	.285
1921	246	21.64	11.37	.525
1922	437	38.95	11.22	.288
1923	421	49.02	8.59	.175
1924	502	41.45	12.11	.292
1925	637	49.70	12.82	.258
1926	622	52.90	11.76	.222
1927	589	49.27	11.95	.243
1928	498	56.62	8.80	.155
1929	597	61.74	9.67	.157
1930	425	44.59	9.53	.214
1931	257	28.61	8.98	.314
1932	88	15.12	5.82	.385
1933	227	25.72	8.83	.343
1934	262	29.18	8.98	.308
1935	342	38.18	8.96	.235
1936	637	53.50	11.91	.223
1937	710	56.64	12.54	.221
1938	342	31.75	10.77	.339
1939	556	52.80	10.53	.199
1940	899	66.98	13.42	.200
1941	1,059	82.84	12.78	.154
1942	1,091	86.03	12.68	.147
1943	1,045	88.84	11.76	.132
1944	952	89.64	10.62	.118
1945	921	79.70	11.56	.145
1946	959	66.60	14.40	.216
1947	871	84.89	10.26	.121
1948	981	88.64	11.07	.125
1949	879	77.98	11.27	.145
1950	1,170	96.84	12.08	.125
Average, 1901-50	X	X	10.75	X
1951	1,215	105.20	11.55	.110
1952	1,070	93.17	11.48	.123
1953	1,222	111.61	10.95	.098
1954	794	88.31	8.99	.102
1955	1,237	117.04	10.57	.090
1956	889	115.22	7.72	.067
1957	1,267	112.71	11.24	.100

See footnote at end of table.

Table 7.—Relationships between manganese apparent consumption (AC) and raw steel production (RSP), 1901-90—Continued

Year	AC (thousand short tons)	RSP (million short tons)	$10^3 \times$ ratio of AC/RSP	$10^9 \times$ ratio of $AC/(RSP)^2$
1958	953	85.25	11.18	0.131
1959	1,061	93.45	11.35	.121
1960	1,077	99.28	10.85	.109
1961	842	98.01	8.59	.088
1962	978	98.33	9.95	.101
1963	1,096	109.26	10.03	.092
1964	1,216	127.08	9.57	.075
1965	1,373	131.46	10.44	.079
1966	1,353	134.10	10.09	.075
1967	1,207	127.21	9.49	.075
1968	1,150	131.46	8.75	.067
1969	1,317	141.26	9.32	.066
1970	1,327	131.51	10.09	.077
1971	1,170	120.44	9.71	.081
1972	1,366	133.24	10.25	.077
1973	1,554	150.80	10.31	.068
1974	1,492	145.72	10.24	.070
1975	1,133	116.64	9.71	.083
1976	1,364	128.00	10.66	.083
1977	1,523	125.33	12.15	.097
1978	1,363	137.03	9.95	.073
Average, 1951-78	X	X	10.18	X
1979	1,250	136.34	9.17	.067
1980	1,029	111.84	9.20	.082
1981	1,027	120.83	8.50	.070
1982	672	74.58	9.01	.121
1983	668	84.62	7.89	.093
1984	627	92.53	6.78	.073
1985	698	88.26	7.91	.090
1986	730	81.61	8.94	.110
1987	699	89.15	7.84	.088
1988	752	99.92	7.53	.075
1989	797	97.94	8.14	.083
1990	695	98.91	7.03	.071
Average, 1960-90	X	X	X	.083
Average, 1901-90	766	75.34	10.17	.135
Cumulative, 1901-90	68,957	6,780.67	X	X

X Not computed.

These two ratios are plotted as a function of time in figure 13. Scatter in the AC/RSP versus time plot appears to be greatest for years prior to 1951, and also the value of AC/RSP averaged over 1901-50 is slightly greater than the average for 1951-78. The dropoff after 1978 is another indication of the changes in efficiency of use of manganese in steelmaking that occurred beginning at about that date. Scatter is less in the $AC/(RSP)^2$ time plot, in which this second ratio appears by the mid-1950's to have reached roughly an asymptotic value suggestive of an empirical relationship, $AC = 10^9 \times (RSP)^2/12$.

The reasonable consistency of the apparent consumption data for 1901-90 allows an overall assessment to be made of the disposition of manganese consumed in the United States for that time interval, which is summarized in table 8 and diagrammed in figure 14. Figure 15 portrays U.S. cumulative raw steel production in 1860-1991 and shows that the predominant quantities of steel were made in open-hearth furnaces and then the basic oxygen furnaces that superseded them. The data upon which this figure is based indicate that 98.5% of the steel produced between 1860 and 1990 was produced in 1901 and later years.

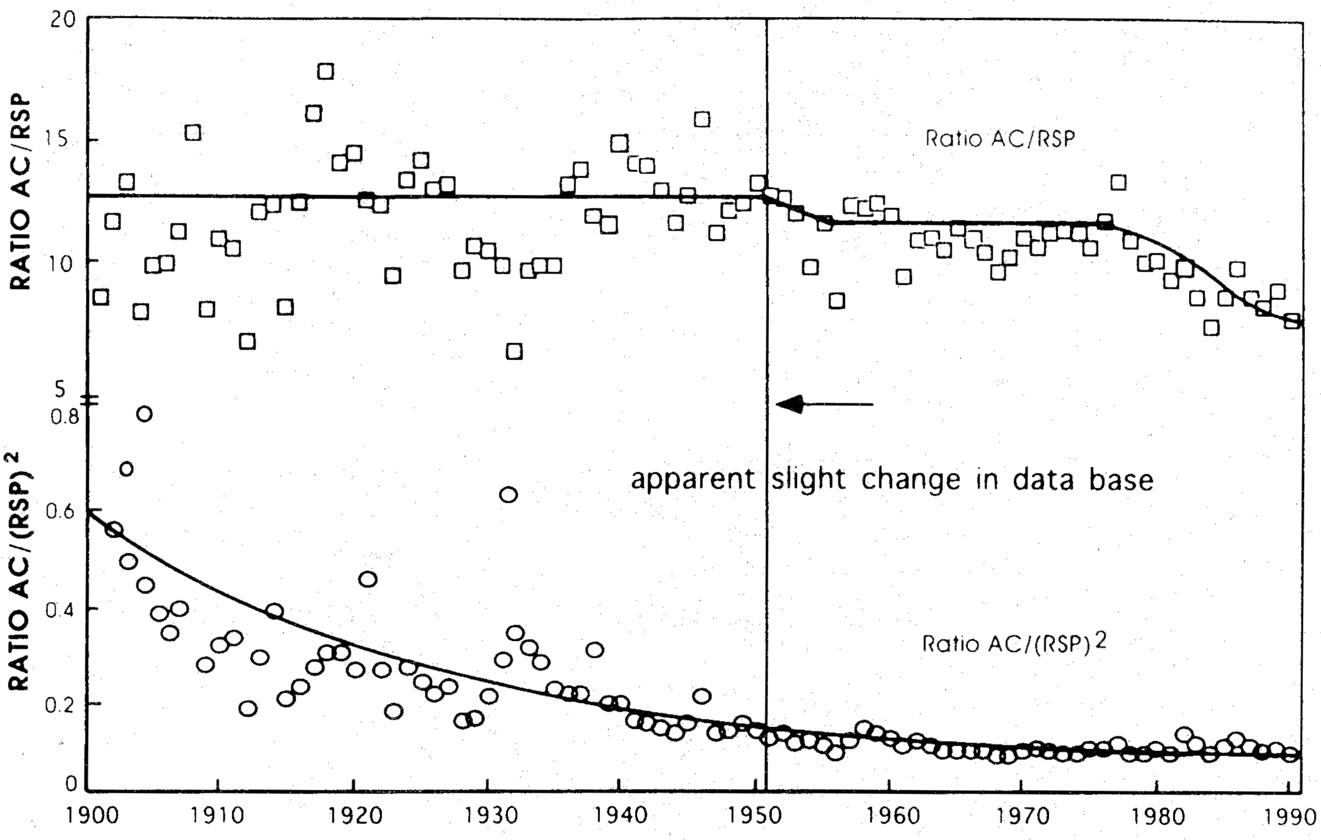


Figure 13.—Relationships between manganese apparent consumption (AC) and raw steel production (RSP), 1901-90.

Other than cumulative raw steel production and manganese apparent consumption, the quantities in table 8 were obtained as follows:

1. Cumulative losses to iron and steel slag: From information previously presented in the section on the iron and steel industry, it was assumed that, on average and for at least most of the period, the rate of loss of manganese to slag could be taken as 14 pounds of manganese per ton of raw steel produced. This gives a factor of 7×10^{-3} tons of manganese per ton of raw steel that when applied to a cumulative raw steel production of 6.78 billion tons (1901-90) calculates to 47.5 million tons of manganese in slag exiting the steelmaking cycle.

2. Manganese contained in obsolete ferrous scrap: The size of the reservoir of steel scrap potentially available to steelmakers has been estimated as 683 million tons as of the end of 1981, which increased at an average annual rate of about 18 million tons during 1976-80 (*7*). Assuming that this inventory increased at the same average rate during 1982-90 as in the immediately preceding 5-year period, the inventory at the end of 1990 would have been 845 million tons. The manganese contained in this inventory can be estimated as 5.9 million tons assuming its average manganese content to have been 0.7%.

3. Cumulative dissipative losses: As already discussed, uses of manganese other than in steelmaking (i.e., in batteries, brick coloring, animal feed, plant fertilizer, and so on) have been inherently dissipative. Collectively, they have been accounting for roughly 10% of manganese consumption, so that the cumulative loss for these uses is taken as one-tenth of total consumption, or 6.9 million tons.

4. Manganese content of the National Defense Stockpile: This quantity is included because stockpile transactions are a part of the apparent consumption calculation. As of the end of 1990, the quantity of manganese contained in the various manganese materials being held in Government inventories was estimated as 2.0 million tons.

Table 8.—Disposition of manganese consumed in the United States, 1901-90

(Million short tons; manganese in terms of contained manganese)

	Quantity	Proportion of cumulative manganese apparent consumption
Cumulative raw steel production	6,780	NAp
Cumulative manganese apparent consumption	69.0	100%
Estimated disposition of manganese:		
Cumulative losses to iron and steel slag	47.5	69%
Contained in obsolete ferrous scrap, 1990	5.9	9%
Cumulative dissipative losses	6.9	10%
Contained in National Defense Stockpile, 1990:	2.0	3%
Accounted for	62.3	[1]90%
Not accounted for	6.7	10%

NAp Not applicable.
[1]Data do not add to subtotal shown because of independent rounding.

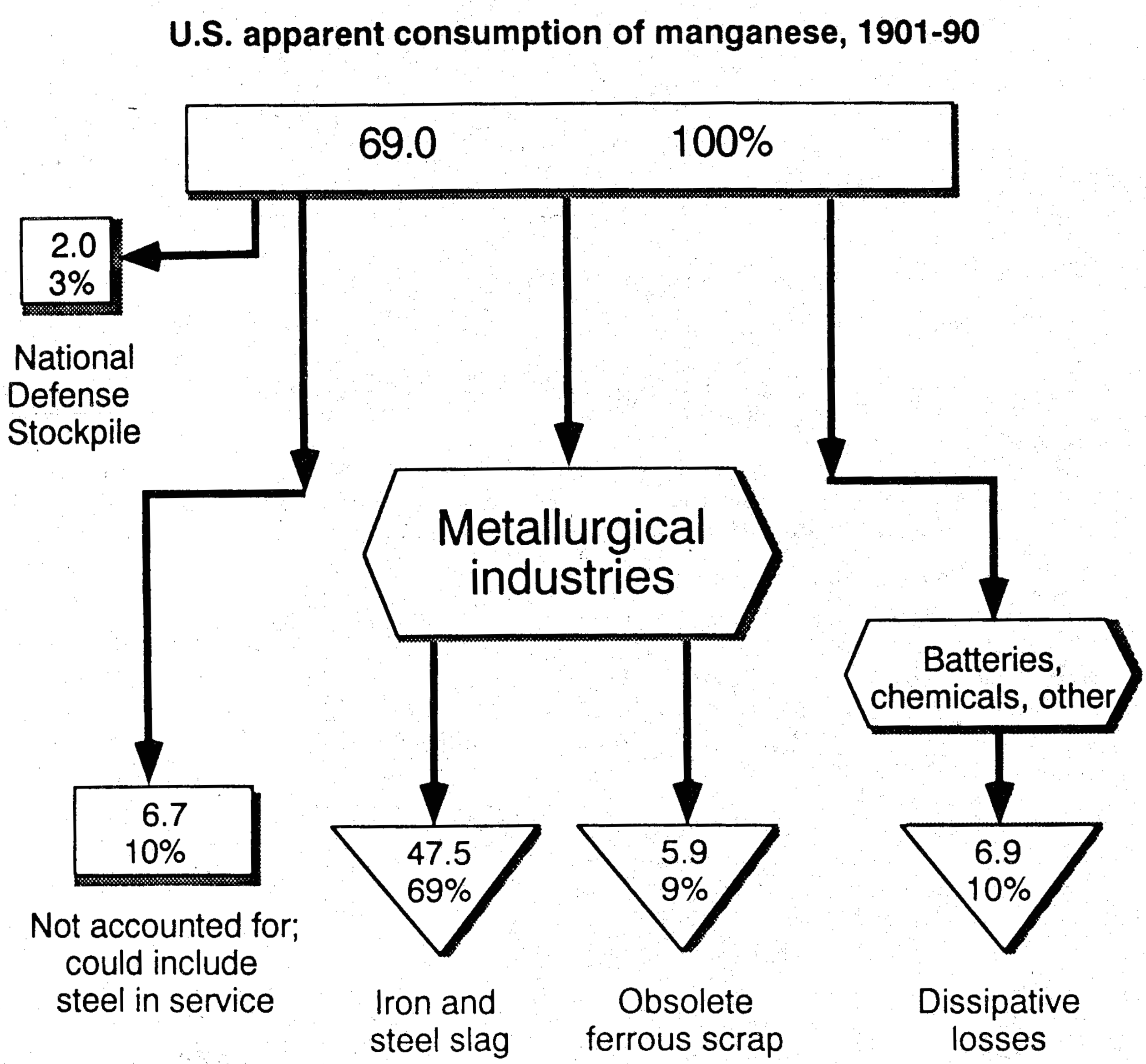
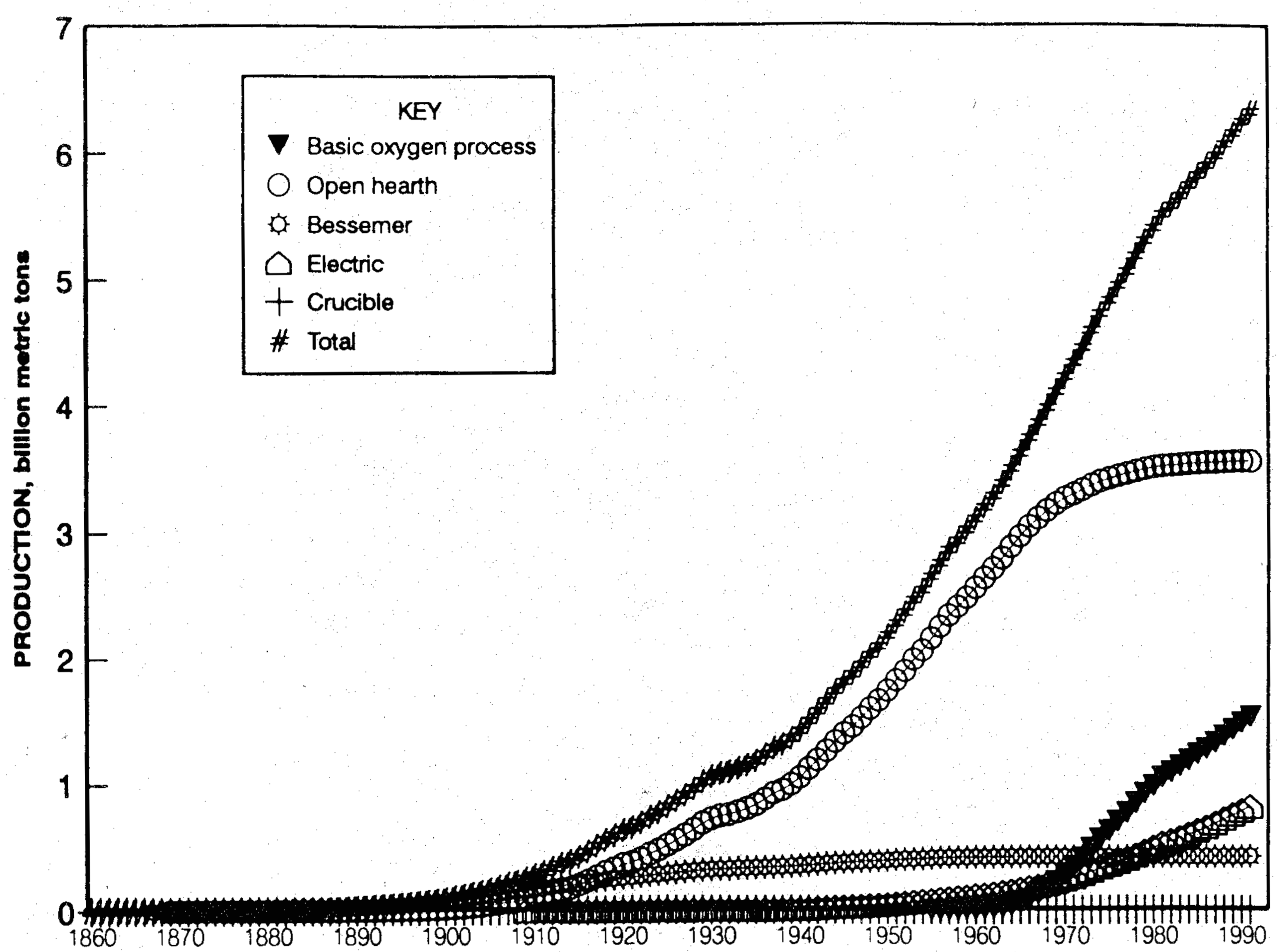


Figure 14.—Disposition of manganese consumed in the United States 1901-90 in million short tons of manganese content.



Source of data: American Iron and Steel Institute.

Figure 15.—Cumulative U.S. raw steel production by process, 1860-1991.

The data in table 8 suggest, perhaps with greater implied than real accuracy, that 90% of U.S. manganese consumption can be assigned to readily identifiable categories, leaving only 10% to be assigned to unidentified processing and other losses or to factors not considered in the construction of this table. Referring to the 1974 manganese materials cycle already discussed, manganese contained in articles in service could be at least a portion of the 10% not accounted for. In this connection, it can be noted that the 6.7 million tons of manganese in this category is roughly 10 times the annual U.S. apparent consumption of manganese of the early 1990's. Accordingly, this quantity corresponds to approximately 10 years of domestic raw steel production at an annual level in the vicinity of 90 million tons, for a total of nearly one billion tons.

The most important ultimate destination of the manganese utilized is iron and steel slag. According to the estimates given in table 8, a quantity of manganese equal to about two-thirds of the manganese units being consumed domestically ultimately becomes more or less immobilized as a minor component in slag from iron and steelmaking. These slags are used in construction, road building, and for other purposes. From time to time, efforts have been made by the Bureau of Mines and others to develop technology for recovering manganese from steel slags because they represent a potential resource of a strategic and critical material (*21*). In World War II, the Germans turned to slag for a source of manganese much needed by their military, at which time the manganese content of steel slags was about twice that in slags from modern oxygen steelmaking. However, ferrous slags are relatively inert, and a commercial method of recovering manganese from them has not been developed, nor seems likely to be.

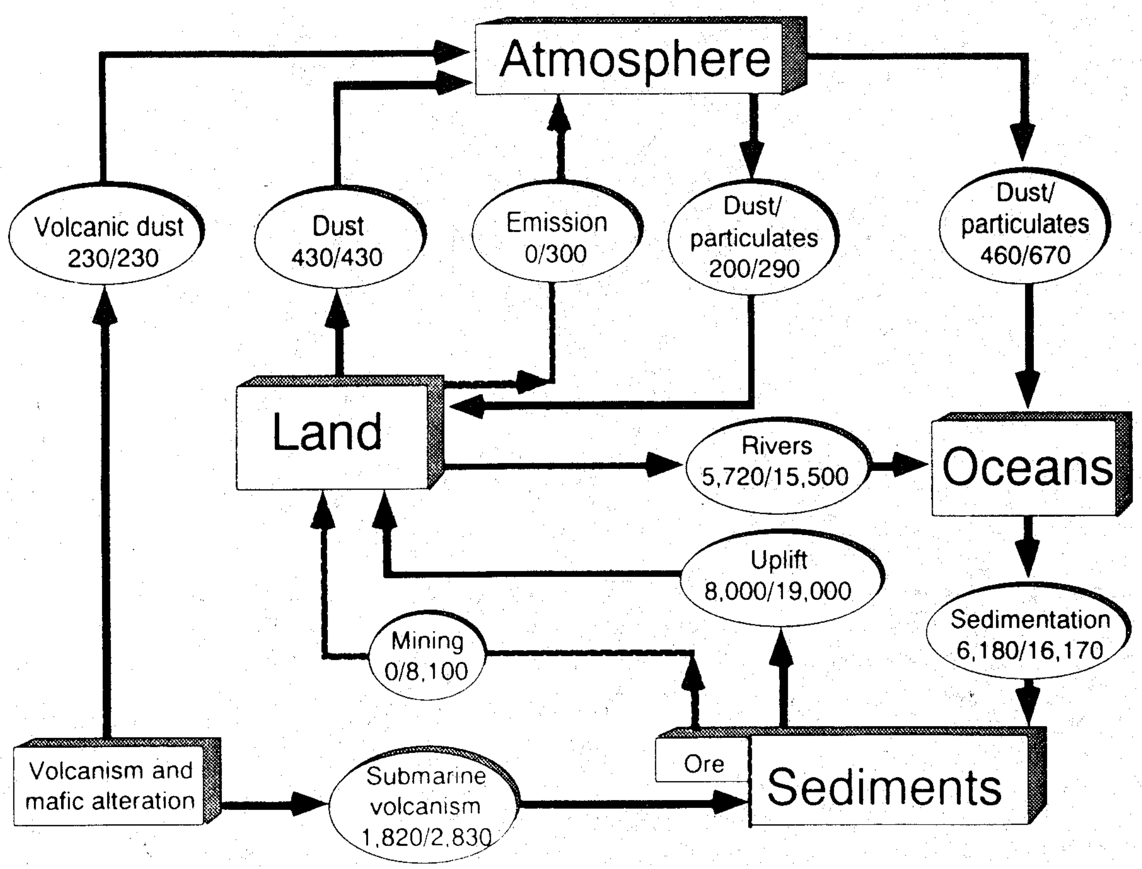
FLOWS FROM NATURAL CAUSES AND EFFECT OF HUMAN ACTIVITIES

Interest has been growing in comparing how the cycling of various metals through the Earth's environment as a result of natural phenomena have been affected by human activities. Part of this interest is because some metals can present a hazard to humans and other forms of life. Manganese is an essential element for people, animals, and plants (*22*). It is not known to have caused environmental damage, nor does manganese exposure pose a general risk to the environment (*23*). Nevertheless, manganese and manganese chemical compounds were among the substances whose releases were required to be reported to the Environmental Protection Agency (EPA) as of 1988.

The diagram of figure 16 gives estimates of conditions prior to and after the imposition of human activities on natural flows, based on a relatively simple model of global cycles for manganese (*24*). According to this treatment, human activities have led to increases of 45% each in total emissions from the land to the atmosphere and conversely in the amount of dust depositing on the land and on the oceans from the atmosphere. Particulate manganese from industrial activities was believed to settle out from the atmosphere near its source (i.e., not to travel long distances), which implies that most of the fallout would be around industrial (steelmaking) centers.

This treatment found the principal change in the global manganese cycle to be in the amount of manganese being carried to the oceans, which was estimated to have increased to 2.7 times the amount prior to humans. This change was not related directly to industrial utilization of manganese but rather to increased runoff resulting from deforestation and agricultural activities.

The details of how these estimates were obtained were not given; thus, answers to some points relating to them cannot be resolved. Two apparent anomalies in figure 16



Solid portions indicate pre-human/present day
Dashed portions indicate human activities

Source: Reference 24, pp. 778-79.

Figure 16.—Pre-human/present-day global fluxes of manganese in thousand metric tons per year.

reflect an effort to maintain mass balances for non-steady-state conditions in the present-day situation. These are increases in uplift of ocean sediments to land and in the flux to sediments from subsea volcanism. Transport of manganese to the oceans is discussed further in appendix C.

The estimate of 300,000 mt/yr for present-day emissions of manganese from land to the atmosphere that are attributable to human activities as given in figure 16 is considerably higher than that which can be projected from data from the toxic release inventory (TRI) program of EPA. TRI data indicate that total (manganese and manganese compounds) U.S. emissions of manganese averaged about 1,890 st/yr in 1987-90 (*25*). Taking U.S. apparent consumption of manganese to have averaged 720,000 st in those years, the U.S. air emission rate for manganese calculates to 2.6×10^{-3}, or 0.26%. If this same rate were assumed to apply globally, for a world manganese consumption of about 9,500,000 st, the air emission rate would be about 25,000 st/yr, or about one-thirteenth that given in figure 16.

The lower estimate is more consistent with estimates published within the past few years by Nriagu and others also directed at assessing the effect of human activities on metals in the environment (*26-28*). Estimates from these publications for global emissions of manganese are presented in table 9 according to natural and anthropogenic sources. (Note: Estimates cited in reference 29, pp. 121-22, differ considerably from those of Nriagu.) Manganese emissions from anthropogenic sources in 1983 were estimated as 38,000 mt. The total of 317,000 mt/yr for emissions from natural sources is about one-half that of 660,000 mt/yr given in figure 16. These later estimates indicate the proportion of total emissions resulting from human activities to have been about 11% as compared with 89% for those from natural causes. A higher percentage of about 33% is indicated by figure 16 for the share of total emissions attributable to human activities.

Nriagu and others also have estimated on a global basis the quantities of manganese being put into water systems and soils as a consequence of human activity, with results as listed in tables 10 and 11. Domestic waste water and sewage discharges were indicated to account for more than one-half the anthropogenic input into water systems. Coal ashes were indicated to account for about two-thirds of the input of manganese into soils.

Combining these various estimates, Nriagu has compared mobilization of manganese in the biosphere by weathering with that caused by human activity (*28*). According to his figures, about 2.5 times as much manganese (4,800,000 mt/yr) is currently being mobilized by weathering as is contained in industrial discharges (1,894,000 mt/yr). He estimates that about 18,000,000 mt/yr of manganese is being mobilized by mining. This quantity is roughly twice that of estimated current annual production (content basis) of manganese ore, which is reasonable considering that overall recoveries can be in the range of 50% to 60%. Perhaps an additional 2 million mt/yr of manganese could be mobilized in production of 900 million mt of iron ore, assuming a recovery also in the range of 50% and an average manganese content of 0.1%.

As noted by Nriagu, only a fraction of the quantity involved in mining and concentrating would be released to the environment. Typically, any releases would be highly localized at the sites of mining and beneficiation, which normally are separated only by a short distance. In domestic extraction of iron ore, which in most cases carries only a fractional percentage of manganese, the waste rock is set aside as a large pile and tailings from grinding are segregated into a settling pond.

Table 9.—Worldwide emissions of manganese

(Thousand metric tons per year)

Agent	Range	Median
NATURAL SOURCES[1]		
Wind-borne soil particles	42 - 400	221
Seasalt spray	.02 - 1.7	0.86
Volcanoes	4.2 - 80	42
Wild forest fires	1.2 - 45	23
Biogenic:		
Continental particulates	4 - 50	27
Continental volatiles	.03 - 2.5	1.3
Marine	.08 - 3.0	1.5
Total	4.11 - 55.5	29.8
Grand total	52 - 582	317
ANTHROPOGENIC SOURCES[2]		
Energy production:		
Coal combustion:		
Electric utilities	1.08 - 6.98	X
Industry and domestic	1.485 - 11.88	X
Oil combustion:		
Electric utilities	.058 - .58	X
Industry and domestic	.358 - 1.79	X
Total	2.981 - 21.23	12.1
Mining	.415 - .83	.62
Smelting and refining:		
Copper-nickel production	.85 - 4.25	2.55
Manufacturing processes:		
Steel and iron manufacturing	1.065 - 28.4	14.7
Waste incineration:		
Municipal	.252 - 1.26	X
Sewage sludge	5 - 10	X
Total	5.252 - 11.26	8.26
Grand total	10.563 - 65.97	38

X Not calculated.
[1]Source: Reference 27.
[2]Sources: References 26 and 28.

Table 10.—Worldwide anthropogenic input of manganese into aquatic ecosystems

(Thousand metric tons per year)

Agent	Range	Median
Domestic wastewater:		
Central	18 - 81	X
Non-central	30 - 90	X
Total	48 - 171	110
Electric powerplants	4.8 - 18	11
Base metal mining and smelting:		
Base metal mining and dressing	.8 - 12	X
Iron and steel	41 - 36	X
Nonferrous metals	2.0 - 15	X
Total	16.8 - 63	40
Manufacturing processes:		
Metals	2.5 - 20	X
Chemicals	2.0 - 15	X
Pulp and paper	.03 - 1.5	X
Total	4.53 - 36.5	21
Atmospheric fallout	3.2 - 20	12
Sewage discharges	32 - 106	69
Grand total	109 - 414	263

X Not calculated.

Sources: References 26 and 28.

Table 11.—Worldwide inputs of manganese into soils

(Thousand metric tons per year)

Agent	Range	Median
Agricultural and animal wastes:		
Agricultural and food wastes	15 - 112	X
Animal wastes, manure	50 - 140	X
Total	65 - 252	158
Logging and wood wastes	18 - 104	61
Urban refuse	7.0 - 42	24
Municipal sewage and organic waste:		
Municipal sewage sludge	4.4 - 11	X
Miscellaneous organic, including excreta	.08 - .63	X
Total	4.48 - 11.63	8.1
Solid wastes from metal fabrication	.41 - 4.9	2.6
Coal ashes	498 - 1,655	1,076
Fertilizers and peat:		
Fertilizer	.13 - .83	X
Peat (agricultural and fuel uses)	5.2 - 17	X
Total	5.33 - 17.83	12
Discarded manufactured products[1]	100 - 500	300
Atmospheric fallout	7.4 - 46	27
Grand total	706 - 2,633	1,670

X Not calculated.

[1]Assumes 1% to 15% of total annual mine production is discarded and/or lost to corrosion.

Sources: References 26 and 28.

The relative insignificance of the quantity of manganese being mobilized by mining as compared with that naturally occurring can be estimated by considering the quantity of manganese in a thin slice of the Earth's crust. The average concentration of manganese in the lithosphere can be taken as 0.085% and the mass of the continental crust as 17.39×10^{24} g (*30*). From this, the manganese content of the Earth's crust can be calculated as 1.48×10^{16} mt. Taking the average depth of the crust to be 40 km, the manganese contained in a layer 30 feet deep (approximately 0.01 km) would be 3.7×10^{12} mt. This amount is 185,000 times the estimated annual mobilization from mining of 20 million mt.

SUMMARY

The main applications of manganese, the forms in which it is employed, and, in brief, the chief features of the domestic and global (see appendix B) manganese industries have been reviewed in this study. The work of others on natural global flows of manganese and the effect of human activities upon them also has been discussed.

The domestic flow patterns of manganese have been described for the principal industries in which it is involved: iron and steel, ferroalloys, dry cell batteries, brick coloring, animal feed and plant fertilizer, and permanganates and other chemicals. Analysis of manganese inputs and outputs was emphasized for iron and steel production. This is the only component of use for which the 1990 industry structure does not significantly restrict the presentation of quantitative information because of the need to protect proprietary data. Ferrous slag from iron and steel production was shown to be a particularly important ultimate destination for human use of manganese. Domestic ore production is noted to have been a relatively minor source for supply of manganese to the U.S. economy.

Available data on U.S. apparent consumption of manganese in 1901-90 indicate a cumulative consumption of about 69 million tons of manganese during a period in which about 6.8 billion tons of raw steel was produced. Distribution in 1990 of the eventual disposition of manganese was estimated to have been about 69% in slag, 10% in dissipative uses, 9% in obsolete ferrous scrap, 3% in U.S. Government inventories, and 10% not accounted for, perhaps including that in articles in service. The

manganese in slag was considered to be immobilized at relatively low concentration. Such slag has been used chiefly in construction and road building.

According to a non-Bureau analysis made prior to this study, the principal change in global manganese flows as a result of human activity is the raising of river runoff of manganese to the oceans to a level 2.7 times the natural base. Deforestation and agricultural activities were indicated to have been the main reasons for the increase.

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APPENDIX A.—MANGANESE UTILIZATION BY DOMESTIC METALLURGICAL INDUSTRIES

STEELMAKING

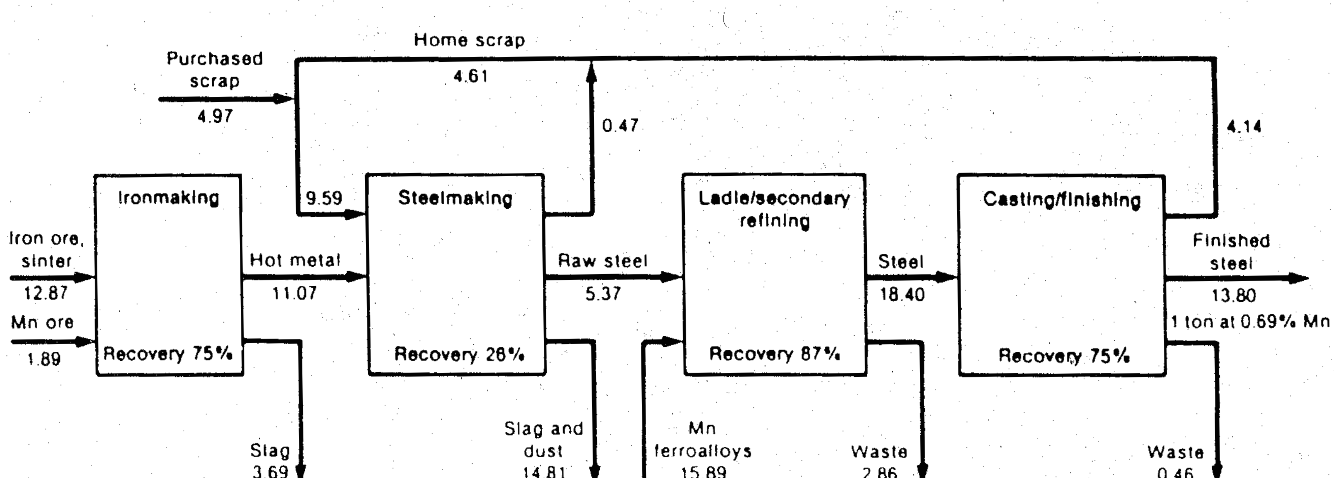
Proceeding from the discovery that manganese could be used to overcome the deleterious effect of sulfur impurity in steel, metallurgists eventually developed the rule of thumb that the manganese content of steel should be a minimum of 20 times its sulfur content (*31*).[1] Applying this rule to steels with sulfur contents typically ranging up to 0.05% (except in resulfurized steels to which sulfur has deliberately been added to improve machinability), the manganese required for sulfur control alone becomes a minimum of about 0.1%. The minimum manganese-to-sulfur ratio for avoidance of hot shortness increases as sulfur content decreases. It has been suggested that, for a steel with only 0.005% sulfur, the ratio should be at least 50, which implies a manganese requirement of at least 0.25% (*32*).

The majority of steel produced in the 20th century has been by way of ore-based integrated steelmaking as principally opposed to scrap-based EAF steel production. Analysis of the use of manganese in steelmaking has focused on integrated methods combining a blast furnace for production of pig iron and a decarburization unit, which lately has been one of various forms of oxygen converter.

[1]Italic numbers in parentheses refer to items in the list of references preceding the appendixes.

The analysis that OTA published in 1985 of manganese in the integrated steelmaking sequence is shown in figure A-1 (*2*). Unfortunately, the terminology used by OTA does not conform to that used by either the domestic (AISI) or international (IISI) statistical programs of the steel industry. Specifically, the material labeled "raw steel" by OTA pertains to the relatively pure liquid iron produced by decarburizing pig iron in an oxygen converter. For the most part in the terminology of AISI and IISI, this liquid iron becomes "raw" or "crude" steel, respectively, when it has been alloyed, adjusted to final composition, and cast into the first solid shape suitable for further processing or sale.

The material in the OTA diagram which most closely corresponds to industry definitions of raw or crude steel is labeled simply "steel." This material becomes "finished steel" when it has been cast and processed. Casting losses would be just a few percent and can be ignored compared to processing or finishing losses evaluated by OTA on the assumption of a 75% recovery. On this basis, the data in the OTA diagram can be converted to pounds of manganese per ton of raw steel (rather than per ton of finished steel) by multiplying them by 0.75. The data in the diagram are based on producing 1.33 tons of raw steel from which finally is obtained 1.0 ton of finished steel.



*Recovery with respect to ferromanganese additions is assumed to be 82 percent, while complete recovery of Mn is assumed for raw steel.

SOURCE: Office of Technology Assessment; and G.R. St. Pierre, et al., *Use of Manganese in Steelmaking and Steel Products and Trends in the Use of Manganese as an Alloying Element in Steels*, OTA contractor report, February 1983.

Source: Reference 2, p. 235.

Figure A-1.—Current pattern of manganese use in steelmaking in pounds of manganese per ton of finished steel.

Similar diagrams for manganese flow in integrated steelmaking were put forth previous to that of the OTA report in a 1980 report of the IISI ("hypothetical integrated plant") (*8*) and in the 1976 report of NMAB (*1*). These diagrams are reproduced in figures A-2 and A-3, respectively. The IISI and NMAB diagrams are on the basis of quantity of manganese per ton of crude or raw steel. The IISI's kilogram-per-metric-ton data are readily converted to pounds per short ton by multiplying them by 2.0. A comparison of the manganese inputs and outputs as given in the three diagrams was presented in table 4 in the main section of this report.

An aspect of slag indicated in the IISI and NMAB diagrams but not in that of OTA is the recycling of converter slag to the blast furnace. This can be an alternative to the use of manganese ore for introducing manganese units into pig iron (*33*). Whether or not converter slag is recycled depends on the raw materials used and the metallurgical preferences observed at individual plants. In some cases, the iron feed materials contain enough manganese that a deliberate addition is not necessary to achieve the manganese content desired in the pig iron, a factor that also varies from plant to plant and from time to time. Manganese contents of about 0.7% have been the target in pig iron production, but the modern tendency is toward lower levels, such as can be promoted by selecting ores low in manganese. Another consideration in steel slag recycling is that the practice may make it difficult to control residual elements. Because phosphorus is such an element and steelmakers are under pressure to produce steels with increasingly lower phosphorus contents, some steelmakers have eliminated or reduced steel slag recycling.

The unit consumption of manganese is indicated in the three diagrams to be in the range of about 10 to 14 pounds per ton of raw steel. The reasonableness of these unit consumption rates can be judged by comparison of projections from them with U.S. apparent consumption of manganese. The OTA estimate for manganese unit consumption is 13.8 pounds per ton of raw steel. This estimate was developed in the 1982-83 period, at which time raw steel production averaged about 80 million tons per year. A corresponding manganese consumption of about 556,000 tons can be calculated, which is 83% of a U.S. apparent consumption of about 670,000 tons during those years. This result seems to agree acceptably with other calculations signifying that the steel industry accounts for about 90% of total manganese consumption.

In assessing apparent consumption, the Bureau has focused on the manganese content of the manganese and manganiferous ores, ferroalloys, and metal consumed. This has been done to avoid the rather unmanageable task of including also the manganese contents of iron feed materials, scrap, and slag that are estimated in the OTA, IISI, and NMAB diagrams. Available data of this type for 1970-90 are discussed later in this appendix. As indicated by the data in table 4, the manganese inputs in the form of manganese ore and ferroalloys roughly equal that in the raw steel produced, which is a reflection of the metallurgy of steelmaking. Stated another way, it is as if the manganese units input as iron feed materials and scrap mostly end up in slag and wastes.

For manganese ferroalloys alone, the diagrams indicate a manganese unit consumption rate of about 10 to 12 pounds per ton of raw steel. This rate or efficiency of use can be compared with and can be seen to be consistent with rates calculated from Bureau statistics on U.S. reported consumption in steelmaking of manganese ferroalloys and metal. These calculated rates have been given in the commodity annual report chapter for manganese since 1942. These data are listed in table A-1 and the principal features are graphed in figure A-4. Because of the relative constancy of unit consumption prior to about the 1980's, it had been almost a principle that steelmaking required the use of 12 to 14 pounds of manganese per ton.

Unit consumption as calculated from reported consumption would be increased more significantly if corrected for incomplete reporting of silicomanganese consumption. This has been a longstanding problem in Bureau statistics, the significance of which can be presumed to have increased since the 1960's along with the rise in steel production in scrap-based EAF's. These so-called "minimills" account for a disproportionate amount of silicomanganese consumption relative to their raw steel output. The effect of this on the 1990 statistics can be appreciated by noting that reported consumption of silicomanganese in steelmaking was 103,451 tons out of a total silicomanganese consumption of 107,950 tons, whereas imports of silicomanganese were 247,439 tons. Internal evaluation indicates the import quantity to be much closer to actual consumption than that reported. Using imports in place of reported consumption of silicomanganese would raise manganese unit consumption by about 1.9 pounds per ton. Thus, in figure A-4, the growth in unit consumption of silicomanganese is greater than that shown, and the position of the line for total unit consumption is lower than actual probably since the 1970's.

Beginning about the 1980's, manganese unit consumption (as reported) dropped by roughly 30% within a few years. The subsequent trend appears to be toward the range of 8 to 9 pounds per ton. The decrease was caused by a number of changes in steelmaking technology and practices that included combined blowing (use of gases such as argon along with the usual oxygen during decarburization), lowered manganese specifications because of desulfurization of hot metal external to the blast furnace, and better recovery of alloying additions during operations referred to as ladle metallurgy. The increase in proportion of steel cast continuously rather than traditionally as ingots also has contributed to decreased unit consumption in recent years.

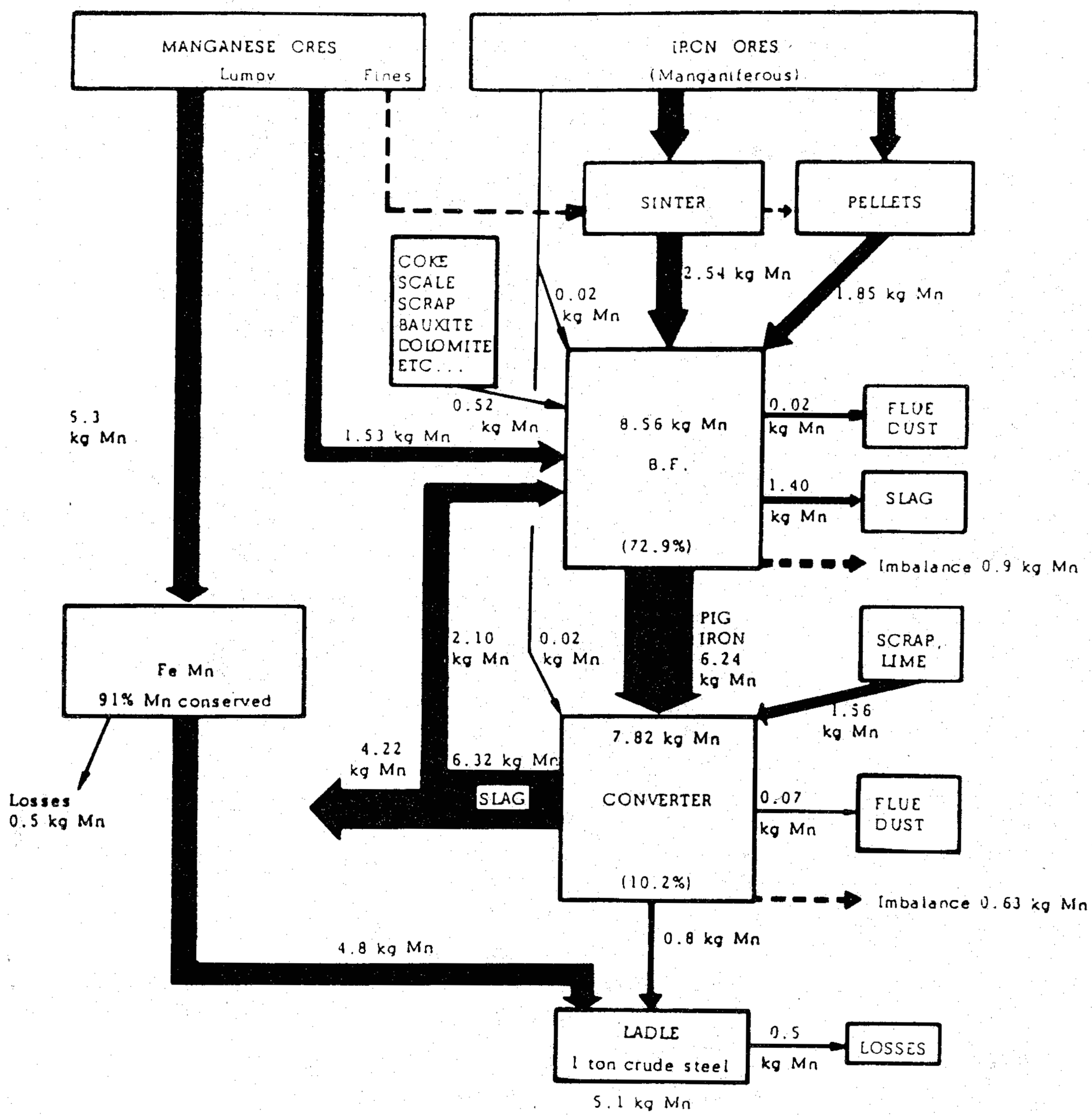
Table A-1.—Unit consumption of manganese in manufacture of steel in the United States, by form used, 1942-90

(Pounds of manganese per ton of raw steel)

Year	FeMn	SiMn	Metal	Spiegel	Ore	Total
1942	11.20	0.60	—	0.60	NA	12.4
1943	11.70	.60	—	.70	0.30	13.3
1944	11.70	.90	—	.60	.10	13.3
1945	12.00	.90	—	.60	.10	13.6
1946	11.10	1.00	—	.50	.10	12.7
1947	11.70	1.00	—	.40	.10	13.2
1948	11.30	1.00	—	.30	.10	12.7
1949	11.80	1.00	—	.30	.10	13.2
1950	12.20	1.00	—	.30	.10	13.6
1951	11.90	1.00	0.05	.25	—	13.2
1952	12.20	1.10	.05	.25	([1])	13.6
1953	12.10	1.15	.05	.20	([1])	13.5
1954	11.40	1.00	.05	.20	([1])	12.7
1955	11.45	1.10	.05	.20	([1])	12.8
1956	11.80	1.10	.10	.20	([1])	13.2
1957	12.00	1.10	.10	.10	([1])	13.3
1958	11.50	1.00	.20	.10	([1])	12.8
1959	11.60	1.20	.20	.10	—	13.1
1960	11.80	1.10	.30	.10	—	13.3
1961	11.70	1.30	.30	.10	—	13.4
1962	12.00	1.40	.20	.10	—	13.7
1963	12.00	1.50	.30	.10	—	13.9
1964	11.80	1.60	.30	.10	—	13.8
1965	11.70	1.70	.30	.10	—	13.8
1966	11.50	1.40	.25	.05	—	13.2
1967	11.70	1.60	.25	.05	—	13.6
1968	11.70	1.60	.25	.05	—	13.6
1969	11.40	1.30	.25	.05	—	13.0
1970	11.50	1.30	.20	.05	—	13.1
1971	11.20	1.30	.25	.05	.20	13.0
1972	11.00	1.20	.25	.05	.10	12.6
1973	11.10	1.30	.25	.05	.20	12.9
1974	11.50	1.40	.25	.05	.10	13.3
1975	11.40	1.60	.20	.03	.02	13.3
1976	10.60	1.40	.20	.01	.01	12.2
1977	10.60	1.30	.20	.02	.03	12.2
1978	10.90	1.40	.20	([2])	([2])	12.5
1979	11.00	1.50	.20	—	([2])	12.7
1980	10.80	1.60	.20	—	—	12.6
1981	10.30	1.50	.20	—	—	12.0
1982	8.70	1.70	.20	—	—	10.6
1983	7.80	1.20	.20	—	—	9.2
1984	7.90	1.40	.20	—	—	9.5
1985	7.70	1.50	.10	—	—	9.3
1986	6.90	1.60	.10	—	—	8.6
1987	6.90	1.60	.10	—	—	8.6
1988	7.00	1.50	.10	—	—	8.6
1989	6.70	1.30	.10	—	—	8.1
1990	6.80	1.40	.10	—	—	8.3

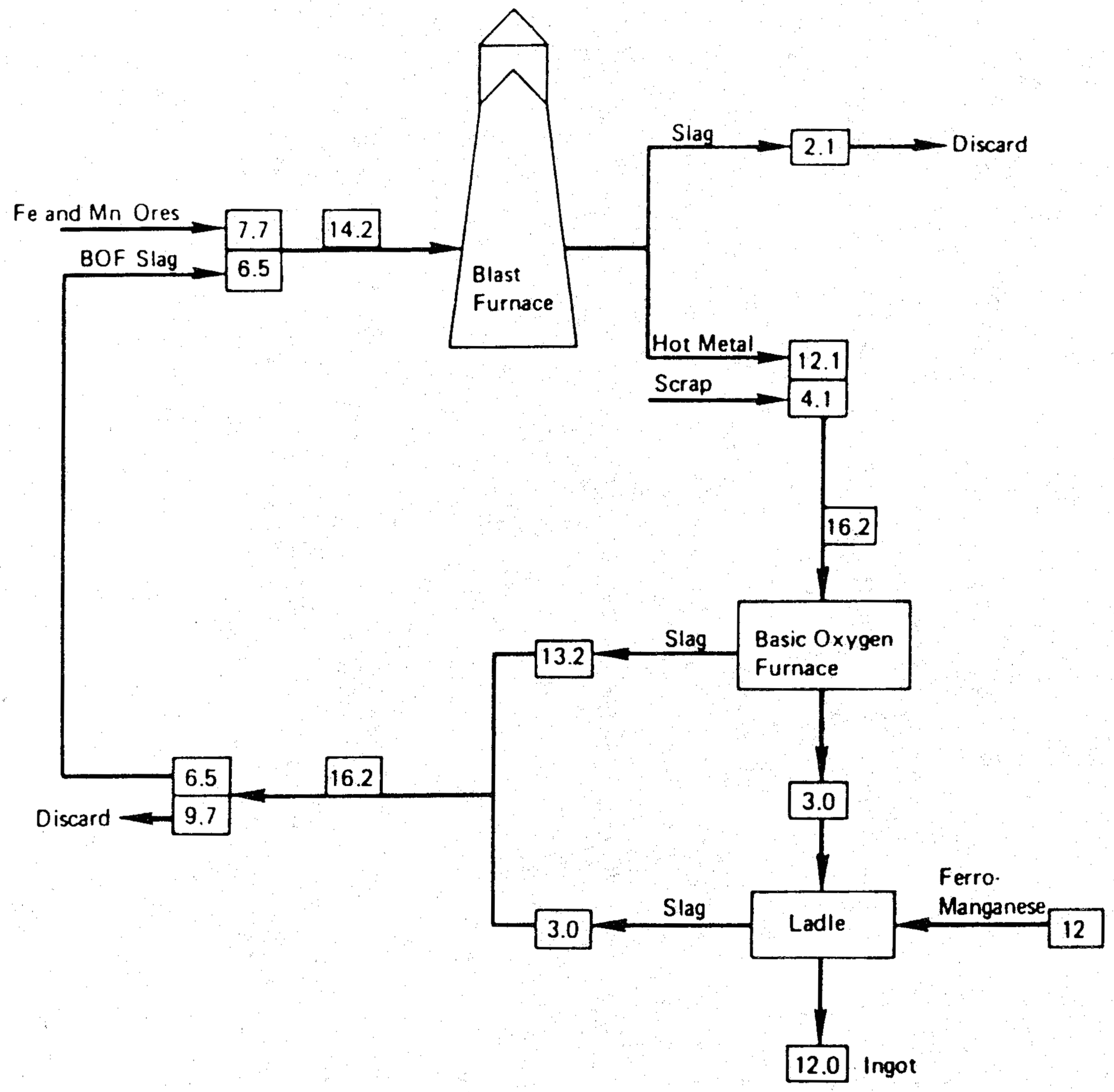
NA Not available.
[1]Included with manganese metal.
[2]Less than 1/2 unit.

NOTE.—Dashes indicate zeros.



Source: Reference 8, p. 29.

Figure A-2.—Manganese balance for integrated steelmaking in kilograms of manganese per metric ton of steel.



Source: Reference 1, p. 22.

Figure A-3.—Empirical flowsheet showing approximate manganese balance for production of steel by blast furnace-basic oxygen process in pounds of manganese per ton of raw steel.

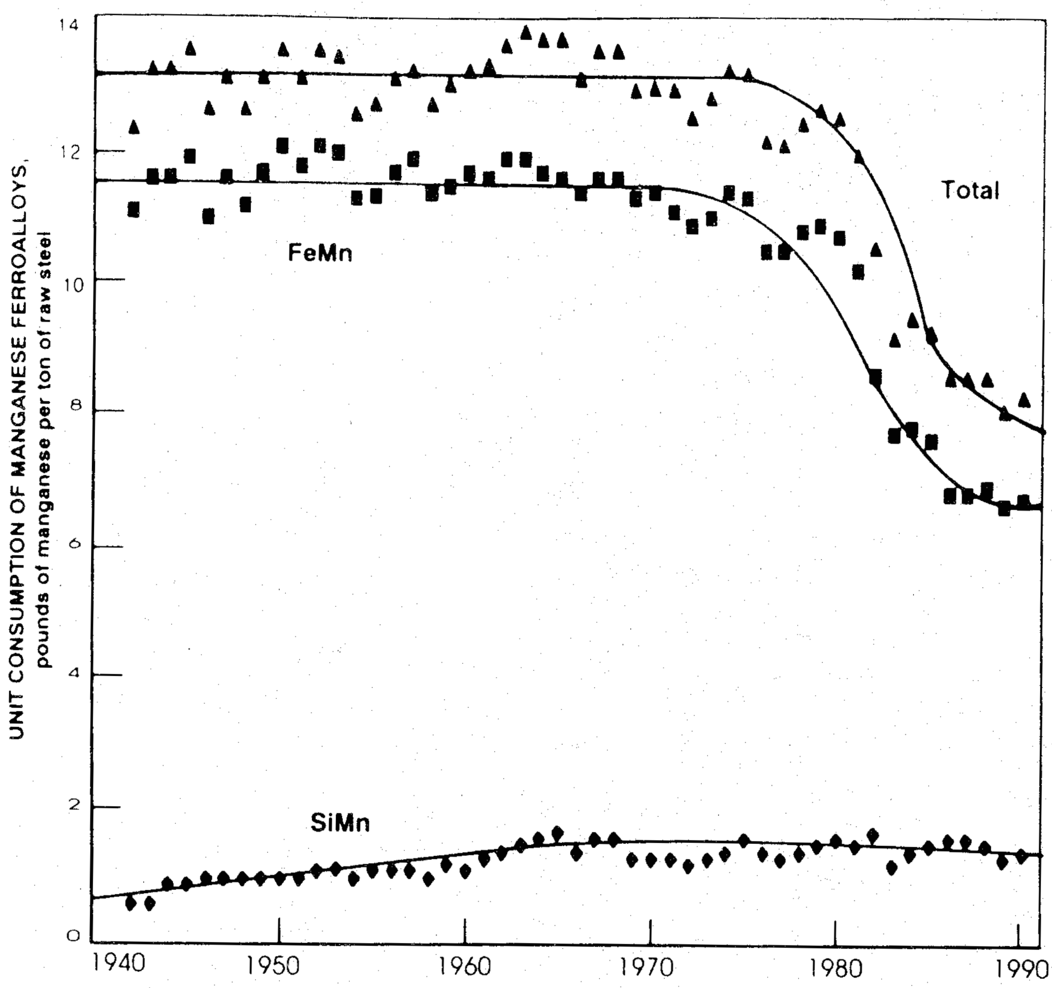


Figure A-4.—Time trends in unit consumption of manganese ferroalloys in U.S. steelmaking, 1942-90.

Returning to consideration of data on inputs and outputs of manganese in integrated steelmaking as in the OTA, IISI, and NMAB diagrams of figures A-1—A-3, information for 1970-90 has been examined with the Bureau as the source except as otherwise noted. The inputs and outputs correspond to those indicated in these diagrams and in table 4. Input data are presented in table A-2 and output data in table A-3, and both are shown graphically in figures A-5 and A-6, respectively. The data have been reduced to the common denominator of pounds of manganese per ton of raw steel. Raw steel production data are those of AISI.

Assumptions and/or limitations of the input data are as follows:

1. Iron ore and agglomerates employed: The manganese content was estimated by applying to total quantity consumed the overall average manganese percentage of U.S. iron feed materials, as given by the American Iron Ore Association. This procedure may have given an underestimate in view of use at some U.S. blast furnaces of Wabush concentrates and/or pellets from Canada containing as much as 2% manganese.

2. Manganese ore: Quantities consumed are those published; manganese contents were obtained or estimated from data on file.

Table A-2.—Manganese inputs in U.S. steelmaking, 1970-90

(Rates in pounds of manganese per ton of raw steel; quantities and contents in millions of short tons)

Year	Raw steel production quantity	Iron ore and agglomerate				Manganese ore				All ore total rate	Purchased scrap			Home scrap			Total scrap rate	Ferro-alloys rate	Total rate
		Gross weight	Content	Average percent Mn	Rate	Gross weight	Content	Average percent Mn	Rate		Gross weight	Average percent Mn	Rate	Gross weight	Average percent Mn	Rate			
1970	131.51	147.833	0.473066	0.32	7.19	0.107733	0.048695	[e]45.20	0.74	7.93	22.929	0.70	2.44	46.394	0.70	4.94	7.38	13.10	28.41
1971	120.44	132.113	.383128	.29	6.36	.187251	.079956	[e]42.70	1.33	7.69	22.011	.70	2.56	42.608	.70	4.95	7.51	13.00	28.20
1972	133.24	144.641	.376067	.26	5.64	.211157	.092381	[e]43.75	1.39	7.03	28.984	.70	3.05	44.431	.70	4.67	7.71	12.60	27.35
1973	150.80	163.942	.475432	.29	6.31	.237807	.102495	[e]43.10	1.36	7.66	32.061	.70	2.98	50.406	.70	4.68	7.66	12.90	28.22
1974	145.72	153.352	.475391	.31	6.52	.222449	.094318	[e]42.40	1.29	7.82	33.653	.70	3.23	47.421	.70	4.56	7.79	13.30	28.91
1975	116.64	127.372	.318430	.25	5.46	.176167	.077232	43.84	1.32	6.78	22.776	.70	2.73	40.060	.70	4.81	7.54	13.30	27.63
1976	128.00	137.879	.330910	.24	5.17	.143761	.063255	44.00	.99	6.16	24.963	.70	2.73	43.464	.70	4.75	7.48	12.20	25.84
1977	125.33	132.005	.330013	.25	5.27	.200803	.086345	43.00	1.38	6.64	26.926	.70	3.01	42.375	.70	4.73	7.74	12.20	26.59
1978	137.03	140.055	.308121	.22	4.50	.219663	.094455	43.00	1.38	5.88	31.374	.70	3.21	44.920	.70	4.59	7.79	12.50	26.17
1979	136.34	140.638	.295340	.21	4.33	.230742	.100673	[e]43.63	1.48	5.81	31.814	.70	3.27	45.376	.70	4.66	7.93	12.70	26.44
1980	111.84	110.154	.198277	.18	3.55	.131516	.058617	44.57	1.05	4.59	29.591	.70	3.70	36.966	.70	4.63	8.33	12.60	25.53
1981	120.83	115.517	.184827	.16	3.06	.147812	.066841	45.22	1.11	4.17	29.919	.70	3.47	38.424	.69	4.39	7.85	12.00	24.02
1982	74.58	68.232	.081878	.12	2.20	.083906	.037168	44.30	1.00	3.19	20.180	.70	3.79	23.518	.68	4.29	8.08	10.60	21.87
1983	84.62	75.217	.090260	.12	2.13	.105505	.047676	45.19	1.13	3.26	25.121	.70	4.16	23.875	.67	3.78	7.94	9.20	20.40
1984	92.53	80.568	.104738	.13	2.26	.116953	.051311	43.87	1.11	3.37	27.100	.70	4.10	24.686	.66	3.52	7.62	9.50	20.49
1985	88.26	78.026	.085829	.11	1.94	.090000	.039432	43.81	.89	2.84	28.634	.70	4.54	24.567	.65	3.62	8.16	9.30	20.30
1986	81.61	64.732	.064732	.10	1.59	.074000	.032134	43.42	.79	2.37	28.690	.69	4.85	20.972	.64	3.29	8.14	8.60	19.11
1987	89.15	73.431	.080774	.11	1.81	.115000	.049252	42.83	1.10	2.92	32.576	.68	4.97	19.089	.63	2.70	7.67	8.70	19.28
1988	99.92	90.033	.135050	.15	2.70	.138000	.059485	43.11	1.19	3.89	35.596	.67	4.77	20.681	.62	2.67	7.34	8.60	19.83
1989	97.94	86.569	.199109	.23	4.07	.135000	.059968	44.42	1.22	5.29	32.888	.66	4.43	18.800	.61	2.34	6.77	8.10	20.16
1990	98.91	82.912	.041456	.05	.84	.090000	.039021	43.36	.79	1.63	35.811	.65	4.71	21.420	.60	2.60	7.31	8.30	17.23

[e]Estimated.

Table A-3.—Manganese outputs in U.S. steelmaking, 1970-90

(Rates in pounds of manganese per ton of raw steel; quantities for raw steel production (RSP) and slag in millions of short tons)

Year	RSP quantity	BF slag		Steel slag		Total slag rate	Raw steel		Total rate
		Quantity	Rate @ 0.3 percent Mn	Quantity	Rate @ 4.0 percent Mn		Average percent Mn	Rate	
1970	131.51	26.147	1.19	7.539	4.59	5.78	0.70	14.00	19.78
1971	120.44	24.812	1.24	8.488	5.64	6.87	.70	14.00	20.87
1972	133.24	25.053	1.13	10.162	6.10	7.23	.70	14.00	21.23
1973	150.80	28.822	1.15	9.739	5.17	6.31	.70	14.00	20.31
1974	145.72	29.880	1.23	8.862	4.87	6.10	.70	14.00	20.10
1975	116.64	25.324	1.30	7.302	5.01	6.31	.70	14.00	20.31
1976	128.00	26.009	1.22	6.588	4.12	5.34	.70	14.00	19.34
1977	125.33	25.716	1.23	6.668	4.26	5.49	.70	14.00	19.49
1978	137.03	28.404	1.24	8.457	4.94	6.18	.70	14.00	20.18
1979	136.34	27.512	1.21	8.252	4.84	6.05	.70	14.00	20.05
1980	111.84	19.041	1.02	6.158	4.40	5.43	.70	14.00	19.43
1981	120.83	15.717	.78	5.770	3.82	4.60	.69	13.80	18.40
1982	74.58	14.752	1.19	4.764	5.11	6.30	.68	13.60	19.90
1983	84.62	13.554	.96	4.832	4.57	5.53	.67	13.40	18.93
1984	92.53	16.776	1.09	5.287	4.57	5.66	.66	13.20	18.86
1985	88.26	15.106	1.03	5.972	5.41	6.44	.65	13.00	19.44
1986	81.61	15.380	1.13	5.689	5.58	6.71	.64	12.80	19.51
1987	89.15	16.221	1.09	5.013	4.50	5.59	.63	12.60	18.19
1988	99.92	15.900	.95	5.714	4.57	5.53	.62	12.40	17.93
1989	97.94	15.489	.95	7.376	6.02	6.97	.61	12.20	19.17
1990	98.91	16.597	1.01	7.552	6.11	7.11	.60	12.00	19.11

3. Scrap: Quantities pertain to those for manufacturers of pig iron and raw steel and castings. Consumption of home scrap was assumed equal to production, which includes a small proportion of obsolete plant scrap such as ingot molds and old equipment and buildings. Consumption of purchased scrap was calculated by deducting the assumed consumption of home scrap from consumption reported as purchased plus home scrap. Particularly in the latter portion of the 1970-90 period, it is noted that these scrap consumption data underestimate that of electric furnace mills. This underestimation might be considered as being offset by inclusion of obsolete plant scrap with home scrap. For home scrap, average manganese content was assumed to be constant at 0.7% through 1980 but then to decline steadily and, as of 1990, to reach 0.6%, approximately the value conservatively estimated by OTA for the year 2000 (*2*, p. 232). For purchased scrap, average manganese content was assumed to follow a similar pattern but with a lag of 5 years; i.e., declining from 0.7% in 1985 to 0.65% as of 1990.

4. BOF slag recycle: No data available; not included nor estimated.

Assumptions and/or limitations for the output data are as follows:

1. Slag: Data are limited to approximately 1970-90 because information on steel slag became available only as of 1966. The National Slag Association was the source of data for 1970-76. The data pertain only to quantities sold or used rather than to those produced. Quantities recycled within steel plants were excluded except for data for 1987-90. The manganese content of blast furnace slag was assumed constant at 0.3% and that of steel slag constant at 4.0%.

2. Raw steel: As with home scrap, average manganese content was assumed to be constant at 0.7% during 1970-80 and then to decline to 0.6% by 1990.

Input trends as graphed in figure A-5 signify a continuous decline in overall manganese rate, which decreased by about one-third between 1970 and 1990. The largest component of the decline was in manganese units charged with iron feed materials, which was estimated to have dropped about 80% in falling from a rate of about 7.1 to 1.4 pounds per ton. Most of this change was because of a decrease of about two-thirds in average manganese content. The lowering of more than one-third in rate of use of manganese ferroalloys (from about 13.0 to 8.2) resulted in an absolute decrease for this input component during 1970-90 almost as great as that for iron feed materials.

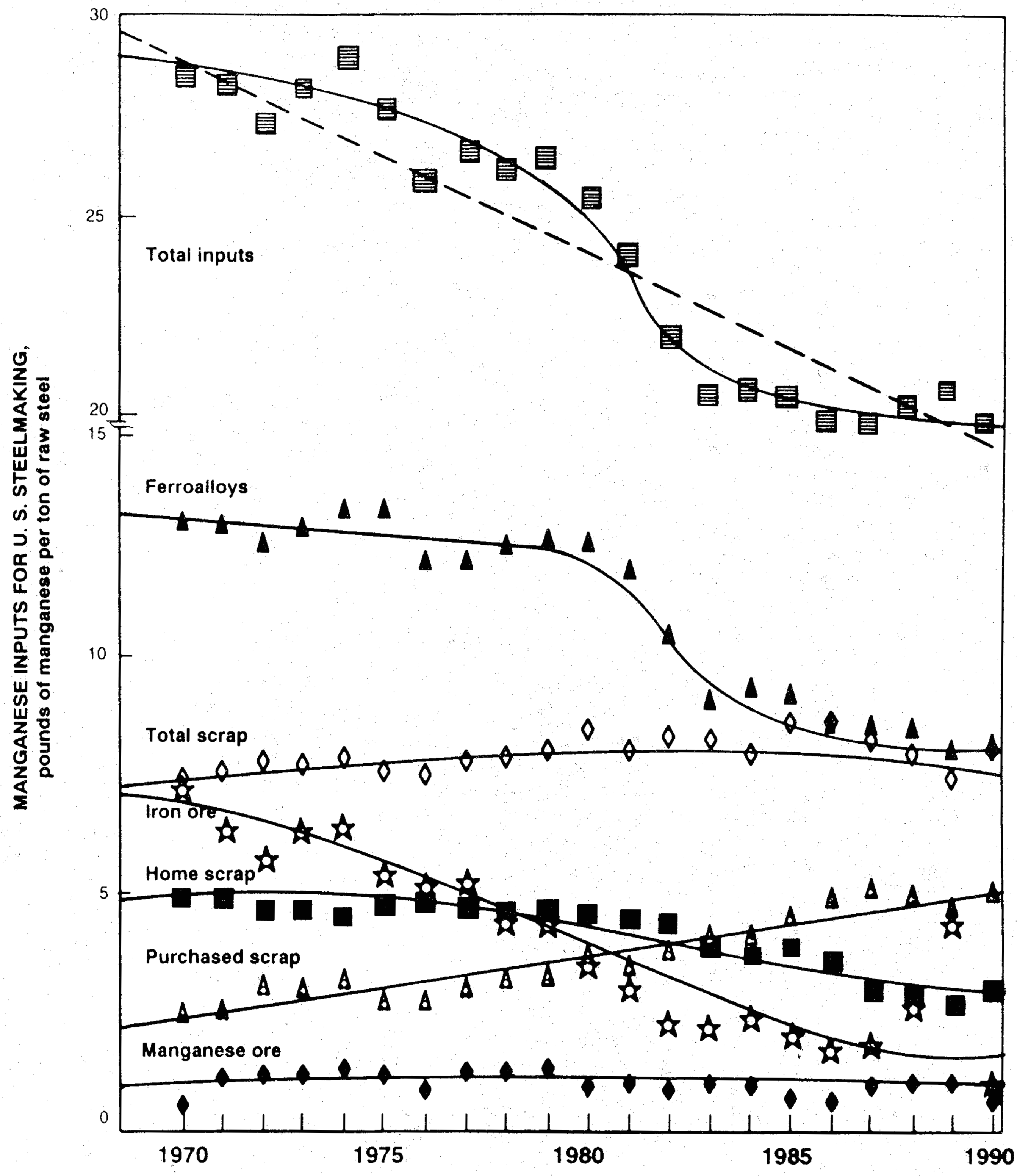


Figure A-5.—Manganese inputs for U.S. steelmaking, 1970-90.

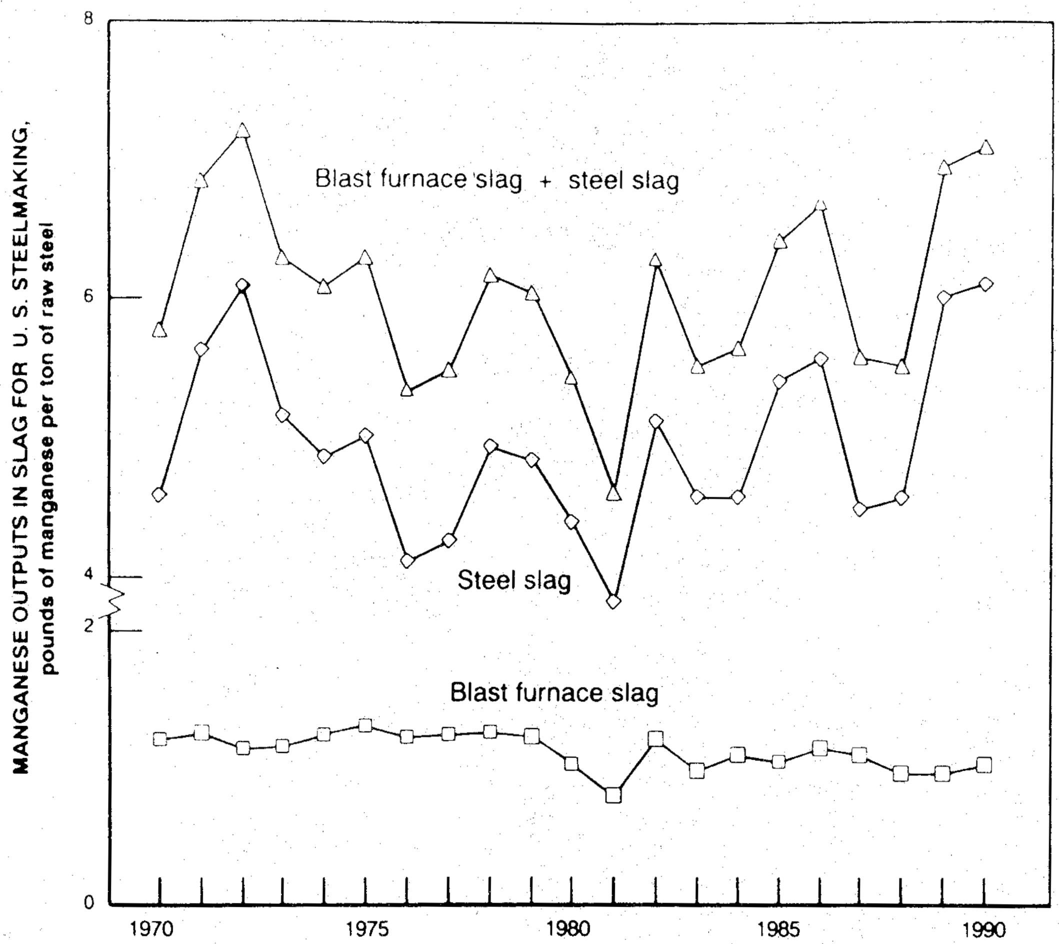


Figure A-6.—Manganese outputs in slag for U.S. steelmaking, 1970-90.

The data for scrap indicated little overall change in manganese input rate during 1970-90, presuming the assumed decline in average manganese content after 1980 to be valid.

Net inputs and outputs as obtained from smoothed graphs of the data are tabulated in table A-4. The sum of the inputs for 1970 and 1980 are in the same general range as those given in the NMAB and OTA analyses for net inputs and outputs, 23.80 (after deducting BOF slag recycle) and 29.83, respectively. The average rate of output via slag for 1970-90 of about 6.2 pounds per ton is only about 53% of that of 11.8 indicated in the NMAB analysis and about 39% that of 16.02 indicated by OTA. Steel slag is the most important component of total slag output because of the relatively greater manganese content in steel slag. As shown in figure A-6, the data suggest a minimum in steel slag output around 1981. Bearing in mind that these data pertain to quantities sold or used, it may have been that quantities of steel slag were allowed to accumulate in the 1970-80 period after which they were increasingly retrieved and marketed.

Table A-4.—U.S. Bureau of Mines data for manganese inputs and outputs for U.S. steelmaking, 1970-90

(Pounds of manganese per ton of raw steel)

	1970	1980	1990
	INPUTS, NET		
Iron/manganese ore	8.40	4.80	2.40
Scrap	7.60	7.80	7.40
Manganese ferroalloys	13.00	12.40	8.20
Total	29.00	25.00	18.00
	OUTPUTS, NET		
Blast furnace slag	1.25	1.15	1.00
Steel slag	5.30	4.70	5.60
Total slag	6.55	5.85	6.60
Raw steel[e]	14.00	14.00	12.00
Total	20.55	19.85	18.60

[e]Estimated.

Source: Smoothed U.S. Bureau of Mines data from graphs.

The data assembled for 1970-90 are not claimed to give a precise picture of changes in rates of manganese input and output during that period. Significant pieces of information are missing, such as slag compositions, and slag recycling has been omitted because of the absence of data. Assuming the trends indicated are valid at least for input, the implication is that the rate of manganese input to steelmaking declined by perhaps one-third. The corollary is that the rate of output to slag and/or to raw steel also had to have declined. The figures in table A-4 for total outputs signify such a trend; the larger values for total inputs in 1970 and 1980 imply a considerable amount of output has been unrecognized and/or underestimated. For 1990, table A-4 indicates that total inputs and outputs of manganese in steelmaking were about 18 pounds per ton.

SLAG AND DUST FROM PRODUCTION OF MANGANESE FERROALLOYS

In the manufacture of manganese ferroalloys in electric furnaces, the quantity of slag from initial furnacing can be estimated as roughly 0.7 ton per ton of product (*34*). The manganese content in slag from manufacture of high-carbon ferromanganese would depend on whether the practice being used was "high-manganese slag" characteristic of an integrated operation or "discard slag" characteristic of a single furnace operation. Manganese contents would be in the vicinity of 30% for the former and about one-half as much for the latter. As noted in figure 9, at Japan Metals and Chemicals Co. (JMC) the final plant slag issuing from the silicomanganese furnace had a manganese content of only 9% and was processed into fertilizers. At Elkem Metals, high-manganese slag is used also as a source of manganese units for manufacture of manganese metal and, in conjunction with that, as the source of manganese sulfate solution used in agriculture. JMC reported that for 1984 the utilization of slag from a plant whose products are similar to those of Elkem Metals was 55% internal recycle, 20% fertilizers, 14% roadbed, and about 6% each wasted and sold as slag (*35*).

The scale at which dust is generated at Elkem Metals' plant might be inferred by reference also to JMC's Takaoka plant, at which, in the early 1980's, about 9,000 tons per year of dust was being collected from a gross production of 220,000 tons of manganese ferroalloys, a quantity including ferroalloy used internally in the plant (*35*). JMC's generation of about 0.040 tons of dust per ton of ferroalloy is of the same order as that of 0.045 calculable from data of Norway's Tinfos Jernverk A/S for silicomanganese operations as of the early 1990's (*36*). At Takaoka, the manganese units in dust were recaptured by sending the dust to a facility in which manganese ores are sintered prior to smelting. Elkem Metals does not have a sintering machine at Marietta, but certain of its dusts yield a Mn_3O_4 product usable as a pigment and for other purposes.

Data of EPA in the 1970's, when air pollution control regulations were being developed, indicate that the rate of emission of particulates from an uncontrolled manganese ferroalloy furnace would be in the range of 290 pounds per ton of product and that the manganese content of the fume would be about 25% (*37*). Assuming high-carbon ferromanganese containing 78% manganese was being produced, these data calculate to a manganese emission equivalent to about 5% of that in the metal being produced. Almost all of this emission would be collected because EPA estimated that a controlled furnace could be expected to have an overall collection efficiency of 99% or better. Data for Tinfos' silicomanganese plant imply a collection efficiency of 99.7%; i.e., 19 tons of dust emitted to the air and 6,400 tons of dry sludge from gas cleaning for an annual production of about 130,000 tons of silicomanganese (*36*).

High-carbon ferromanganese has not been manufactured in a blast furnace in the United States since 1977, but some points about how the process compared with electric furnace smelting may be of interest. For technology just after World War II, a smelting yield of about 85% or similar to that of the electric furnace was stated (*38*). For that time and prior to emissions control, manganese losses were said to be about 8% each to slag and stack gas. Shortly thereafter, effective procedures were worked out and installed such that dust in the gas could at least be captured, briqueted, and stored (*39*). Domestic ferromanganese blast furnaces appeared to have had a slag rate of about 0.8 ton of slag per ton of product while achieving slag manganese contents of about 7% (*40*).

APPENDIX B.—MANGANESE PRODUCTION AND UTILIZATION IN FOREIGN COUNTRIES

World production of manganese ore at the beginning of the 20th century was at the level of 1 million tons, gross weight basis. By the late 1980's, annual production approached 30 million tons. Throughout the 20th century, the bulk of ore production has been concentrated in relatively few countries. In any given year, the top five producing countries accounted for roughly three-fourths or more of production. On the basis of the Chiatura and Nikopol' manganese basins, the former U.S.S.R. has consistently been either the largest or a leading producer since about 1930, except around the period of World War I and the Bolshevik revolution. Brazil and India also have consistently been among the leading countries for ore output; their relative importance has been more in the first rather than the latter part of the century. China and the Republic of South Africa have emerged as leading producers in the second half of the century. The absolute and relative importance of the top five producers in any given year is presented at 5-year intervals during 1910-90 in tables B-1 and B-2. Detailed data on production by country in 1987-91 are given in table B-3.

Development of several significant and mostly new manganese deposits after World War II altered the international supply pattern for manganese ore, especially for higher grade material, such that Australia, Brazil, Gabon, and the Republic of South Africa became the most important sources aside from flows largely within the bloc of nations aligned with the U.S.S.R. The first of these developments was the Amapa deposit in northern Brazil, from which exports began in 1957. This was followed in the 1960's by development of the Groote Eylandt deposit in Australia's Northern Territory and the Moanda deposit in Gabon. During the 1960's and 1970's, several major mines based on the enormous manganese deposits of the Kalahari Field in South Africa's Northern Cape Province were opened.

As of 1990 and shortly thereafter, with recognition of division of the former U.S.S.R. into a number of independent republics, ore production was concentrated in 10 countries. In most of them, a large majority of the output was by only one or two companies or operations: Australia, Groote Eylandt Mining Co. Pty. Ltd. (GEMCO) plus recently Portman Mining Ltd. in Western Australia; Brazil, Cia. Vale do Rio Doce (CVRD) (including Urucum Mineração S.A.) and Indústria e Comércia de Minérios S.A. (ICOMI) plus a number of relatively small mines; China, mainly in the southeastern Provinces; Gabon, Compagnie Minière de l'Ogooué S.A. (COMILOG); Georgia, mining of the Chiatura Basin; Ghana, Ghana National Manganese Corp.; India, more than 200 mines, with Manganese Ore India Ltd. the most prominent company; Mexico, Cía. Minera Autlán de C.V. (Autlán); Republic of South Africa, The Associated Manganese Mines of South Africa Ltd. (AMMOSAL) and Samancor Ltd.; and Ukraine, mining of the Nikopol' Basin.

While the combined output of Georgia and Ukraine positioned the former U.S.S.R. as the world's leading ore producer, the overall average manganese content of the ore has dropped to about 30%, and only a portion of the concentrates are of relatively high quality. Similarly, China's ore production rivals that of the Republic of South Africa for second largest on the basis of gross tonnage, but the content corresponding to China's gross weight production is estimated as only about 20%. In recent years, Australia, Gabon, and the Republic of South Africa have accounted for most of the higher grade ore traded internationally.

Manganese ore is upgraded mainly by smelting it into the intermediate products of ferromanganese and silicomanganese. As of 1990, this conversion was carried out in all of the major ore-producing countries except for Gabon. In addition, manganese ferroalloy smelters were located in a number of countries where ore is not produced. As already mentioned, the United States formerly was a major producer but now is only a minor producer. This change exemplifies the tendency for manganese ferroalloy production to become concentrated in ore-producing countries.

Among countries with the largest output, prominent ferroalloy producers as of 1990 were as follows: Brazil, Cia. Paulista de Ferro-Ligas (a number of plants); China, about 10 main plants; France, Société du Ferromanganèse de Paris-Outreau (SFPO); Georgia, Zestafoni Ferroalloy Works; Germany, Thyssen Stahl AG; Japan, Japan Metals & Chemicals Co. Ltd. and Mizushima Ferroalloy Co. Ltd.; Mexico, Autlán; Norway, Elkem A/S; Republic of South Africa, Metalloys Ltd., a subsidiary of Samancor; and Ukraine, Nikopol' Ferroalloy Works. As with ore production, the output of Georgia combined with the much larger production from Ukraine had made the former U.S.S.R. by far the world's largest producer of manganese ferroalloys. These new republics are the only European countries in which ferroalloy production can be considered as integrated with ore production. Data on world production of manganese ferroalloys during 1987-91 are given in table B-4, which indicates that nearly twice as much ferromanganese is produced in electric furnaces as in blast furnaces.

Table B-1.—Manganese ore: world production for top five producing countries, 1910-90, in terms of quantity

(Thousand short tons, gross weight, unless otherwise specified)

Country	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990
Austria	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Australia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2,204	*	*
Belgian Congo	*	*	*	*	*	*	*	*	*	509	*	*	*	*	*	*	*
Brazil	280	319	500	366	228	*	345	270	*	*	1,101	1,539	2,071	2,377	2,515	2,781	2,200
China	*	*	*	*	*	*	*	*	*	*	1,323	*	*	*	*	2,900	3,500
Cuba	*	*	*	*	*	*	*	218	*	*	*	*	*	*	*	*	*
Czechoslovakia	*	*	55	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Egypt	*	*	86	*	*	96	*	*	*	*	*	*	*	*	*	*	*
French Morocco	*	*	*	*	*	*	*	*	317	*	*	*	*	*	*	*	*
Gabon	*	*	*	*	*	*	*	*	*	*	*	1,411	1,602	2,475	2,366	2,579	2,900
German Empire	88	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ghana/Gold Coast	*	*	*	400	500	483	488	786	798	604	*	*	*	*	*	*	*
India	897	505	825	940	936	723	980	*	989	1,774	1,321	1,815	1,820	1,738	*	*	*
Italy	*	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Japan	*	29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
South Africa, Republic of	*	*	*	*	162	105	454	*	872	649	1,316	1,728	2,954	6,359	6,278	3,969	4,048
Spain	*	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
U.S.S.R.	806	*	*	746	1,592	2,629	3,086	2,481	2,200	5,228	6,473	8,351	7,541	9,324	10,750	10,900	9,700
United States	*	*	106	110	*	*	*	182	*	*	*	*	*	*	*	*	*
Total, for top five[1]	2,089	882	1,572	2,563	3,418	4,036	5,354	3,937	5,176	8,764	11,534	14,844	15,988	22,273	24,113	23,129	22,348
Total	2,173	973	1,801	2,628	3,848	4,382	6,238	4,674	6,200	11,920	14,989	19,557	20,087	27,175	29,086	27,948	27,192
Total, top five countries as percentage of world total	96.13%	90.60%	87.27%	97.52%	88.83%	92.10%	85.83%	84.25%	83.48%	73.52%	76.95%	75.90%	79.59%	81.96%	82.90%	82.76%	82.19%

*Did not end up as one of five countries for that particular year but is part of the grand total.

[1]Data may not add to totals shown because of independent rounding.

Source: U.S. Bureau of Mines: Minerals Yearbooks—Manganese and Manganiferous Ores (1915-42), Manganese (1943-90); Manganese Chapter of Mineral Facts and Problems (1980 and 1985 editions)

Table B-2.—Manganese ore: world production for top five producing countries, 1910-90, in terms of percentage

(Percentage of thousand short tons, gross weight, for each country per grand total per year)

Country	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990
Austria	0.77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Australia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	7.58	*	*
Belgian Congo	*	*	*	*	*	*	*	*	*	4.27	*	*	*	*	*	*	*
Brazil	12.89	32.73	27.78	13.93	5.93	*	5.53	5.78	*	*	7.35	7.87	10.31	8.75	8.65	9.95	8.09
China	*	*	*	*	*	*	*	*	*	*	8.83	*	*	*	*	10.38	12.87
Cuba	*	*	*	*	*	*	*	4.67	*	*	*	*	*	*	*	*	*
Czechoslovakia	*	*	3.06	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Egypt	*	*	4.77	*	*	2.19	*	*	*	*	*	*	*	*	*	*	*
French Morocco	*	*	*	*	*	*	*	*	5.11	*	*	*	*	*	*	*	*
Gabon	*	*	*	*	*	*	*	*	*	*	*	7.21	7.98	9.11	8.13	9.23	10.66
German Empire	4.07	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ghana/Gold Coast	*	*	*	15.23	13.00	11.02	7.83	16.82	12.87	5.07	*	*	*	*	*	*	*
India	41.29	51.87	45.78	35.78	24.32	16.50	15.71	*	15.95	14.88	8.81	9.28	9.06	6.40	*	*	*
Italy	*	1.47	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Japan	*	2.94	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
South Africa, Republic of	*	*	*	*	4.21	2.39	7.28	*	14.06	5.44	8.78	8.84	14.71	23.40	21.58	14.20	14.89
Spain	*	1.59	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
U.S.S.R.	37.11	*	*	28.40	41.36	60.00	49.48	53.09	35.48	43.86	43.19	42.70	37.54	34.31	36.96	39.00	35.67
United States	*	*	5.88	4.19	*	*	*	3.89	*	*	*	*	*	*	*	*	*
Total, for top five countries as percentage of world total[1]	96.13	90.60	87.27	97.52	88.83	92.10	85.83	84.25	83.48	73.52	76.95	75.90	79.59	81.96	82.90	82.76	82.19

*Did not end up as one of five countries for that particular year but is part of the grand total.
[1]Data may not add to totals shown because of independent rounding.

Source: U.S. Bureau of Mines: Minerals Yearbooks—Manganese and Manganiferous Ores (1915-42), Manganese (1943-90); Manganese Chapter of Mineral Facts and Problems (1980 and 1985 editions).

Table B-3.—Manganese ore: world production, by country, 1987-91[1]

(Thousand short tons)

Country[2]	Range percent Mn[e,3]	Gross weight					Metal content				
		1987	1988	1989	1990	1991[e]	1987	1988	1989	1990	1991[e]
Australia[4]	37-53	2,043	2,189	2,341	[r]2,116	[5]1,634	972	[e]1,041	1,111	[r]1,002	773
Brazil[6,7]	30-50	2,279	2,194	2,293	[r,e]2,756	2,400	842	841	871	[r]1,047	910
Bulgaria	29-35	42	[r]38	[r]36	[r,e]55	50	12	11	[r]12	[r,e]18	16
Chile	30-40	35	48	48	44	44	12	16	15	[r]14	14
China[6,8]	20-30	2,900	3,500	[r]3,700	[r,e]3,600	3,700	580	700	[r]740	[r]720	740
Gabon[6,9]	50-53	2,649	2,485	2,858	[r]2,671	2,300	1,223	1,147	1,319	[r]1,233	1,060
Ghana[6]	30-50	303	286	308	[r]272	300	108	106	121	[r]106	115
Hungary[6,10]	30-33	86	89	93	[r]66	72	28	29	29	[r]21	22
India[6,9,11]	10-54	1,435	1,469	1,471	[r]1,502	1,400	534	547	548	[r]564	530
Iran[6]	25-35	[r]69	[r]82	[r]89	[r]60	72	[r]22	[r]25	[r]26	[r]18	22
Mexico[12]	27-50	[e]425	[e]489	[e]435	[r,e]403	200	161	186	165	[r]153	76
Morocco[6]	50-53	47	33	35	[r]54	65	25	18	19	[r]29	34
Romania[e,10]	30	72	72	66	[r]61	55	21	21	20	19	17
South Africa, Republic of[6,9]	30-48 +	[r]3,631	[r]4,434	[r]5,384	[r]4,852	[5]3,465	[r]1,520	[r]1,825	[r]2,253	[r]2,107	1,508
U.S.S.R.	29-30	[r]10,313	[r]10,040	[r]10,076	[r,e]9,400	8,800	3,100	[e]3,000	[r,e]3,020	[r,e]2,800	2,600
Yugoslavia	25-45	46	44	43	[r]56	44	16	[e]15	15	[r]20	15
Other[e,13]	NAp	[r]29	[r]50	[r]47	[r]68	65	[r]12	[r]20	[r]20	[r]30	28
Total	NAp	[r]26,404	[r]27,542	[r]29,323	[r]28,036	24,666	[r]9,188	[r]9,548	[r]10,304	[r]9,901	8,480

[e]Estimated. [r]Revised. NAp Not applicable.

[1]Table includes data available through May 11, 1992. Data pertain to concentrates or comparable shipping product, except that, in a few instances, the best data available appear to be for crude ore, possibly after some upgrading.

[2]In addition to the countries listed, Colombia, Cuba, Panama, Peru, and Sudan may have produced manganese ore and/or manganiferous ore, but available information is inadequate to make reliable estimates of output levels. Low-grade ore not included in this table has been reported as follows, in thousand short tons, gross weight: Argentina (19%-30% Mn), 1987—7, 1988—10, 1989—7, 1990—6 (estimated), and 1991—6 (estimated); and Czechoslovakia (about 17% Mn), an estimated 1 in each year.

[3]May be for average content of each year's production rather than for content of typical products.

[4]Metallurgical ore.

[5]Reported figure.

[6]Gross weight reported; metal content estimated.

[7]Reported gross-weight figures are the sum of (1) sales of direct-shipping manganese ore and (2) production of beneficiated ore, both as reported in Anuário Mineral Brasileiro.

[8]Includes manganiferous ore.

[9]Calculated metal content includes allowance for assumed moisture content.

[10]Concentrate.

[11]Much of India's production grades below 35% Mn; average content was reported as 38% Mn in 1985.

[12]Estimated product total, mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications.

[13]Category represents the combined totals of Greece, Indonesia, Italy (from wastes), Japan, the Republic of Korea, Pakistan, the Philippines, Thailand, Turkey, and Zambia.

Source: U.S. Bureau of Mines Commodity Annual Report for Manganese, 1991.

Table B-4.—World production of ferromanganese and silicomanganese, 1987-91[1]

(Thousand metric tons, gross weight)

Country	1987 Ferromanganese BF	1987 Ferromanganese EF	1987 Ferromanganese Total[2]	1987 SiMn	1987 Total[2]	1988 Ferromanganese BF	1988 Ferromanganese EF	1988 Ferromanganese Total[2]	1988 SiMn	1988 Total[2]
Argentina	—	22	22	12	34	—	20	20	12	32
Australia	—	51	51	43	93	—	58	58	44	103
Belgium[e]	—	90	90	—	90	—	95	95	—	95
Brazil	—	155	155	188	343	—	181	181	193	374
Bulgaria[e, 4]	—	31	31	—	31	—	31	31	—	31
Canada[e, 4]	—	165	165	—	165	—	161	161	—	161
Chile	—	7	7	1	8	—	7	7	1	8
China[e]	200	[3]116	316	220	536	220	[3]89	309	220	529
Czechoslovakia[e, 4]	—	97	97	—	97	—	95	95	—	95
France[6]	296	23	319	31	350	324	22	346	59	405
Germany[4, 7]										
Eastern states[e]	—	65	65	—	65	—	67	67	—	67
Western states[e, 8]	156	25	181	—	181	209	35	244	—	244
India	—	173	173	38	211	—	138	138	53	191
Italy	—	37	37	75	112	—	39	39	[e]69	108
Japan	—	332	332	92	424	—	378	378	107	485
Korea, North[e, 4]	—	70	70	—	70	—	70	70	—	70
Korea, Republic of	—	58	58	—	58	—	76	76	—	76
Mexico	—	161	161	80	241	—	165	165	80	245
Norway	—	192	192	237	429	—	361	361	233	594
Peru	—	2	2	—	2	—	1	1	—	1
Philippines[e]	—	—	—	—	—	—	—	—	—	—
Poland[4]	95	4	99	—	99	91	3	94	—	94
Portugal[e]	—	17	17	8	25	—	10	10	5	15
Romania[e]	—	81	8	39	120	—	80	80	40	120
South Africa, Republic of	—	315	315	282	597	—	447	447	248	695
Spain[e]	—	50	50	35	85	—	48	48	38	86
Taiwan	—	17	17	19	36	—	26	26	31	57
U.S.S.R.[e]	[3]593	438	1,031	1,300	2,331	[3]604	454	1,058	1,300	2,358
United Kingdom	92	—	92	—	92	107	—	107	—	107
United States[9]	—	102	102	—	102	—	W	—	—	—

Country	1989 Ferromanganese BF	1989 Ferromanganese EF	1989 Ferromanganese Total[2]	1989 SiMn	1989 Total[2]	1990 Ferromanganese BF	1990 Ferromanganese EF	1990 Ferromanganese Total[2]	1990 SiMn	1990 Total[2]	1991[e] Ferromanganese BF	1991[e] Ferromanganese EF	1991[e] Ferromanganese Total[2]	1991[e] SiMn	1991[e] Total[2]
Argentina	—	26	26	17	43	—	24	24	22	45	—	24	24	22	45
Australia	—	[e]67	67	55	122	—	[e]70	70	65	135	—	55	55	50	105
Belgium[e]	—	95	95	—	95	—	90	90	—	90	—	90	90	—	90
Brazil	—	181	181	208	389	—	171	171	217	387	—	[3]169	169	[3]272	441
Bulgaria[e, 4]	—	30	30	—	30	—	—	—	—	—	—	—	—	—	—
Canada[e, 4]	—	185	185	—	185	—	185	185	—	185	—	45	45	—	45
Chile	—	7	7	([5])	7	—	7	7	([5])	7	—	7	7	1	8
China[e]	240	120	360	240	600	240	130	370	240	610	250	140	390	250	640
Czechoslovakia[e, 4]	—	100	100	—	100	—	102	102	—	102	—	90	90	—	90
France[6]	346	27	373	[e]59	432	320	37	357	62	419	320	30	350	30	380
Germany[4, 7]											200	95	295	—	295
Eastern states[e]	—	67	67	—	67	—	65	65	—	65	—	NA	NA	—	NA
Western states[e, 8]	230	45	275	—	275	230	38	268	—	268	200	NA	NA	—	NA
India	—	158	158	72	230	—	[e]160	160	[e]75	235	—	160	160	75	235
Italy	—	41	41	[e]47	88	—	45	45	[e]56	101	—	44	44	55	99
Japan	—	394	394	122	516	—	452	452	77	529	—	[3]464	464	[3]87	551
Korea, North[e, 4]	—	70	70	—	70	—	70	70	—	70	—	70	70	—	70
Korea, Republic of	—	85	85	—	85	—	84	84	—	84	—	85	85	—	85
Mexico	—	168	168	99	267	—	186	186	52	238	—	190	190	50	240
Norway	—	221	221	270	491	—	213	213	228	441	—	[3]173	173	[3]227	400
Peru	—	1	1	—	1	—	[e]1	1	—	1	—	1	1	—	1
Philippines[e]	—	—	—	—	—	—	—	—	—	—	—	5	5	—	5
Poland[4]	90	1	91	—	91	71	5	76	—	76	70	5	75	—	75
Portugal[e]	—	[3]13	13	—	13	—	[3]12	12	—	12	—	12	12	—	12
Romania[e]	—	80	80	40	120	—	80	80	40	120	—	70	70	20	90
South Africa, Republic of	—	403	403	258	661	—	404	404	234	638	—	255	255	245	500
Spain[e]	—	50	50	40	90	—	52	52	38	90	—	50	50	40	90
Taiwan	—	31	31	27	58	—	44	44	21	64	—	[3]40	40	[3]13	53
U.S.S.R.[e]	[3]609	414	1,022	1,300	2,322	600	410	1,010	1,300	2,310	550	370	920	1,100	2,020
United Kingdom	140	—	140	—	140	143	—	143	—	143	140	—	140	—	140
United States[9]	—	W	—	—	—	—	W	—	—	—	—	W	—	—	—

See footnotes at end of table.

Table B-4.—World production of ferromanganese and silicomanganese, 1987-91[1]—Continued

(Thousand metric tons, gross weight)

Country	1987					1988					1989					1990					1991[e]				
	Ferromanganese			SiMn	Total[2]	Ferromanganese			SiMn	Total[2]	Ferromanganese			SiMn	Total[2]	Ferromanganese			SiMn	Total[2]	Ferromanganese			SiMn	Total[2]
	BF	EF	Total[2]			BF	EF	Total[2]			BF	EF	Total[2]			BF	EF	Total[2]			BF	EF	Total[2]		
Venezuela	—	—	—	28	28	—	—	—	34	34	—	—	—	32	32	—	—	—	[e]30	30	—	—	—	30	30
Yugoslavia	—	38	38	43	81	—	45	45	47	93	—	34	34	53	86	—	32	32	61	93	—	20	20	50	70
Zimbabwe	—	8	8	—	8	—	[e]2	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total[2]	1,433	2,943	4,376	2,771	7,146	1,555	3,205	4,759	2,813	7,573	1,656	3,113	4,767	2,939	7,706	1,604	3,169	4,772	2,818	7,590	1,530	2,758	4,288	2,616	6,905

[e]Estimated. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in total.
[1]For ferromanganese, the production process is categorized as blast furnace (BF), and electric furnace (EF).
[2]Data may not add to totals shown because of independent rounding.
[3]Reported figure.
[4]Data for ferromanganese includes silicomanganese, if any.
[5]Less than 1/2 unit.
[6]Data for silicomanganese includes silicospeigeleisen, if any.
[7]Totals for Germany in 1991, include data for Eastern and Western states.
[8]Data for blast furnace ferromanganese includes spiegeleisen, if any.
[9]Data for ferromanganese includes silicomanganese and manganese metal.

NOTE.—Dashes indicate zeros.

Source: U.S. Bureau of Mines Commodity Annual Report for Iron and Steel, 1991.

Because a high percentage of manganese consumption is associated with steel production, the main consuming countries for manganese are readily identified as the industrialized countries. Comprehensive data on manganese consumption by country are not available. To a first approximation, manganese consumption can be taken to be proportional to raw steel production. Data on steel production by country in 1987-91 are presented in table B-5. The quantity of manganese used per ton of steel produced varies somewhat from country to country. Factors causing differences include the particular steelmaking technology being employed, the product mix, and economic philosophy. Steelmakers in the United States, Japan, and Western Europe are considered to be relatively efficient in their use of manganese in steelmaking, whereas those in the former U.S.S.R. are believed to have been relatively inefficient (*13*, p. 345).

Consumption of manganese in nonmetallurgical applications is presumed to be relatively universal and basically population related. Manufacture of manganese products to be used other than in the steel industry tends to be country specific. For example, dry cell batteries are used worldwide, but the synthetic manganese dioxide used in the alkaline variety of such cells was produced in the early 1990's only in Australia, Brazil, China, Greece, India, Ireland, Japan, the Republic of South Africa, Spain, the former U.S.S.R., and the United States. Potassium permanganate was produced only in China, Czechoslovakia, Germany, India, Japan, Spain, and the United States; production in the former U.S.S.R. was stopped in 1990. Manganese metal is used mostly for alloying with aluminum, to a lesser degree in steelmaking, and for other purposes. In 1990, the only producing countries were Brazil, China, Japan, the Republic of South Africa (much the largest producer), the former U.S.S.R., and the United States.

Table B-5.—Raw steel:[1] world production, by country, 1987-91[2]

(Thousand metric tons)

Country[3]	1987	1988	1989	1990	1991[e]
Albania[e]	[r]85	[r]110	[r]112	[r]65	35
Algeria	[r]1,378	[r]1,301	[r]943	[r]767	700
Angola[e]	10	10	10	10	10
Argentina	3,633	[r]3,652	[r]3,909	[r]3,634	[4]2,966
Australia	6,129	6,399	6,735	6,666	[4]6,018
Austria	4,301	4,560	4,718	4,292	4,186
Bangladesh[5]	82	81	86	[e]90	90
Belgium	9,787	11,222	10,948	11,426	[4]11,332
Brazil	22,231	24,536	25,018	20,572	22,617
Bulgaria	[r]3,045	2,875	2,899	[r]2,185	2,000
Canada	[r]14,737	[r]14,866	[r]15,458	[r]12,281	[4]12,987
Chile	726	909	800	[r]772	[4]805
China	[r]56,280	[r]59,430	61,200	[r]66,100	[4]70,570
Colombia	689	754	706	733	700
Cuba	402	314	336	270	270
Czechoslovakia	15,356	15,319	15,465	[r]14,877	[4]12,133
Denmark	606	650	625	610	[4]633
Dominican Republic	88	75	55	36	[4]39
Ecuador	25	24	23	[r]20	[4]20
Egypt	[r]1,433	[r]2,025	[r]2,114	[r]2,235	2,541
El Salvador	13	11	[r]12	[e]13	12
Finland	2,669	2,798	2,921	2,861	2,456
France	[r]17,693	[r]19,122	[r]19,335	[r]19,032	[4]18,437
Germany, Federal Republic of:					
Eastern states	8,243	8,131	7,829	5,587	NA
Western states	36,248	41,023	41,073	38,435	NA
Total	44,491	49,154	48,902	44,022	[4]42,169
Greece	907	959	958	[r]1,050	[4]980
Guatemala	21	23	23	[e]23	20
Honduras[e]	7	7	[r]8	[r]8	8
Hong Kong[e]	280	300	320	350	350
Hungary	3,621	3,583	3,356	[r]2,963	1,900
India[6]	[r]13,121	[r]14,309	[r]14,608	[r]14,963	16,394
Indonesia	1,453	2,050	[r,e]2,400	[r,e]2,800	3,250
Iran	[r]839	[r]978	[r]1,081	[r]1,425	[4]2,203

See footnotes at end of table.

Table B-5.—Raw steel:[1] world production, by country, 1987-91[2]—Continued

(Thousand metric tons)

Country[3]	1987	1988	1989	1990	1991[e]
Iraq[e]	—	50	300	150	20
Ireland	220	271	324	326	[4]293
Israel[e]	[4]116	120	118	144	164
Italy	22,859	23,760	25,213	25,439	[4]25,007
Jamaica	[r]21	[r]28	[r]37	[r]24	25
Japan	98,513	105,681	107,908	110,339	[4]109,649
Jordan	[e]240	17	14	[e]14	14
Korea, North[e]	6,500	8,000	8,000	8,000	8,000
Korea, Republic of	16,782	19,117	21,873	23,125	26,001
Libya	—	—	—	500	500
Luxembourg	3,301	3,659	3,721	3,561	[4]3,379
Malaysia[e]	[4]750	550	[r]880	[r]900	900
Mexico	7,642	7,779	7,851	[r]8,726	[4]7,883
Morocco[e]	6	7	7	7	7
Netherlands	5,082	5,518	5,681	5,412	[4]5,174
New Zealand	409	460	608	765	700
Nigeria	184	192	213	220	200
Norway	837	907	641	384	438
Pakistan[e]	1,100	1,000	1,000	1,000	1,000
Paraguay	13	62	[r]63	[r]63	60
Peru	503	481	401	[r]284	350
Philippines[e]	250	[4]331	300	300	250
Poland	17,148	16,873	15,094	[r]13,625	[4]10,439
Portugal	732	811	[r]762	[r]746	[4]564
Qatar	492	527	585	571	550
Romania	13,885	[r]14,496	14,415	[r]9,787	7,000
Saudi Arabia	1,365	1,614	1,810	1,833	1,850
Singapore	422	413	495	489	490
South Africa, Republic of	8,991	8,837	[r]9,337	[r]8,691	[4]9,358
Spain	11,691	11,685	12,684	12,705	12,700
Sweden	4,595	4,779	[e]4,700	4,454	4,248
Switzerland	870	825	916	970	955
Syria[e]	70	70	70	70	70
Taiwan	5,949	8,313	9,047	[r]9,747	[4]10,957
Thailand	534	552	689	685	711
Trinidad and Tobago	361	[r]361	294	[r]372	425
Tunisia	196	150	194	200	200
Turkey	7,044	7,982	7,934	[r]9,462	[4]9,336
U.S.S.R.	161,887	163,037	[r]160,096	[r]154,414	132,666
United Kingdom	17,425	19,013	18,813	17,908	[4]16,511
United States	80,877	90,650	88,852	89,726	[4]79,738
Uruguay	30	29	47	40	40
Venezuela[6]	[r]3,297	[r]3,165	[r]2,941	[r,e]3,000	3,100
Vietnam[e]	110	115	115	120	120
Yugoslavia	4,367	4,487	4,500	3,609	2,200
Zimbabwe	515	602	592	580	600
Total	[r]734,319	[r]779,782	[r]786,219	[r]770,638	733,673

[e]Estimated. [r]Revised. NA Not available.

[1]Steel formed in first solid state after melting, suitable for further processing or sale; for some countries, includes material reported as "liquid steel," presumably measured in the molten state prior to cooling in any specific form.

[2]Table includes data available through June 29, 1992.

[3]In addition to the countries listed, Burma, Ghana, Libya, and Mozambique are known to have steelmaking plants, but available information is inadequate to make reliable estimates of output levels.

[4]Reported figure.

[5]Data are for year ending June 30 of that stated.

[6]Includes steel castings.

NOTE.—Dashes indicate zeros.

Source: U.S. Bureau of Mines Commodity Annual Report for Iron and Steel, 1991.

APPENDIX C.—MANGANESE INPUT TO THE OCEANS

Transport of manganese to the oceans, particularly by means of rivers, is, as was shown in figure 16, one of the more significant aspects of manganese flow in the biosphere subject to the effects of human activities. The mechanism of this transport is a complex process about which more knowledge is being developed continuously. A schematic diagram of the various routes by which manganese reaches the oceans and its progression thereafter is shown in figure C-1. River transport is predominantly by means of suspended particulates. Average concentrations are estimated as 8.2 parts per billion for manganese dissolved in river water and 1,050 parts per million as particulates; i.e., roughly the same as in soil. Transport as dissolved manganese accounts for only about 2% of total river transport (*41*). Data cited in one source indicates that the present-day gross global fluvial flux of manganese to the ocean margins as particulate matter is about 16 million mt/yr and only about 400,000 mt/yr as dissolved manganese (*29*, p. 157).

Events at the river/ocean interface can be quite involved, as portrayed schematically in figure C-2 for the estuary of the St. Lawrence River. Estuaries act as a block to the transport of material from river to ocean and retain about 90% of the river flux. In the case of manganese, the result is that the net global fluvial flux to the oceans is about 1,600,000 mt/yr as particulates and about 300,000 mt/yr as dissolved manganese (*29*, pp. 158-161).

Manganese concentration gradients in the oceans reflect input of manganese from rivers. Measurements of the variation of manganese concentration with depth typically show maximums in the ocean surface layers, particularly close to continents (*42*). Geographic variations in concentration are observed, such as associated with atmospheric input in that the highest concentrations of dissolved manganese in surface waters of the North Atlantic are found in latitudes receiving large inputs of Saharan dust (*29*, p. 185). The usual pattern in oceans is that manganese concentration decreases as depth increases, and fairly uniform and low concentrations are attained in deep waters (*43*).

The relatively new field of plate tectonics indicates input of hydrothermal manganese from upwelling fluids at ocean spreading centers to be a major source of manganese to the oceans. In one study, the hydrothermal manganese flux was estimated to be three to four times as great as that of dissolved manganese from rivers; i.e., 900,000 mt/yr hydrothermal versus 250,000 mt/yr hydrogenous (*44*). In another study, an even higher hydrothermal to fluvial ratio of about 30 was estimated, 7,700,000 versus 270,000 mt/yr (*29*, p. 176).

Over geologic time, precipitation from marine environments has resulted in the formation of manganiferous deposits as nodules on ocean floors and crusts on undersea mountains. These formations constitute sizable metal resources whose recovery has been the subject of considerable research and development work. Manganese is the principal metal constituent of nodules and crusts; for both, the manganese content averages about 25% at the sites of greater interest. Iron is the second most abundant metal at an average content of roughly 15%. The greatest potential value attaches to the nickel, copper, and cobalt contents of the nodules and to the cobalt and nickel contents of the crusts. Metal content is variable, but, for the more favorable locations, typical contents in nodules are about 1% each for nickel and copper and 0.2% for cobalt and in cobalt-manganese crusts about 1% for cobalt and 0.5% for nickel.

Investigations so far indicate that the Pacific Ocean possesses the most promising accumulations of nodules and crusts. For nodules, attention has centered on those at ocean depths of 3,600 to 5,500 meters in the Clarion-Clipperton (C-C') zone southeast of Hawaii. For crusts, attention has centered on those on seamounts in an Exclusive Economic Zone (EEZ) such as that of the Johnston Islands southwest of Hawaii. Crusts have the advantage of lesser depth, which can be 2,000 meters or less. Nodules are discrete, pea- to potato-size bodies resting on or partially submerged in sediments, whereas crusts are coatings perhaps 5 cm thick that follow the contours of the underlying surface on which they form.

Nodules and crusts represent a vast manganese resource. For example, it has been estimated that 2.1 billion mt of dry nodule material is potentially recoverable from the C-C' zone (*45*, p. 66). At a manganese content of 25%, this implies about 500 million mt of manganese, which is comfortably more than the 370 million mt reserve estimate of the U.S. Bureau of Mines for the Republic of South Africa, the giant among sources of terrestrial reserves. The three single best areas of the C-C' zone have been estimated to contain a total of 283 million dry mt of nodules (*46*). At a manganese content of 27%, this constitutes a manganese resource of 76 million mt, which is equivalent to about 9 years of total world production at the 1990 rate. A similar magnitude can be estimated for crust resources. For crusts in the EEZ of the Johnston Islands proposed for lease sale, the manganese resource was estimated as 81 million mt in crusts about 2.5 cm thick having an average manganese content of about 24% (*47*).

Technology for mining nodules, a gathering operation, has advanced to the stage of optimization and adaptation to commercial scale, while that for crust mining, a cutting and scraping operation, is still under development (*48*, *49*). Extractive technology for processing nodules and crusts has been relatively well worked out, since techniques similar to those for land deposits are suitable for both. Studies of the possible environmental impacts of mining and processing nodules and crusts indicate that the principal concern would be with processing, with relatively minimal impacts expected for mining.

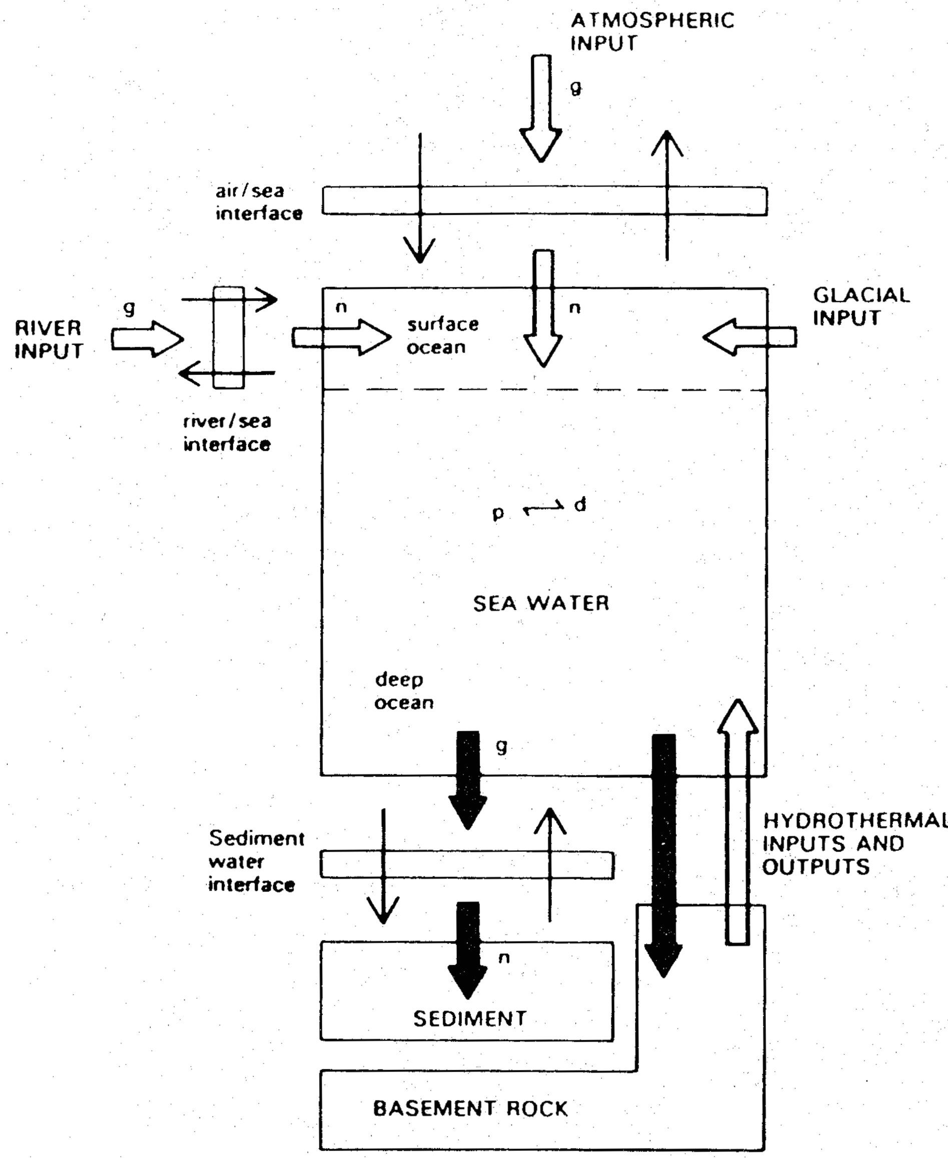
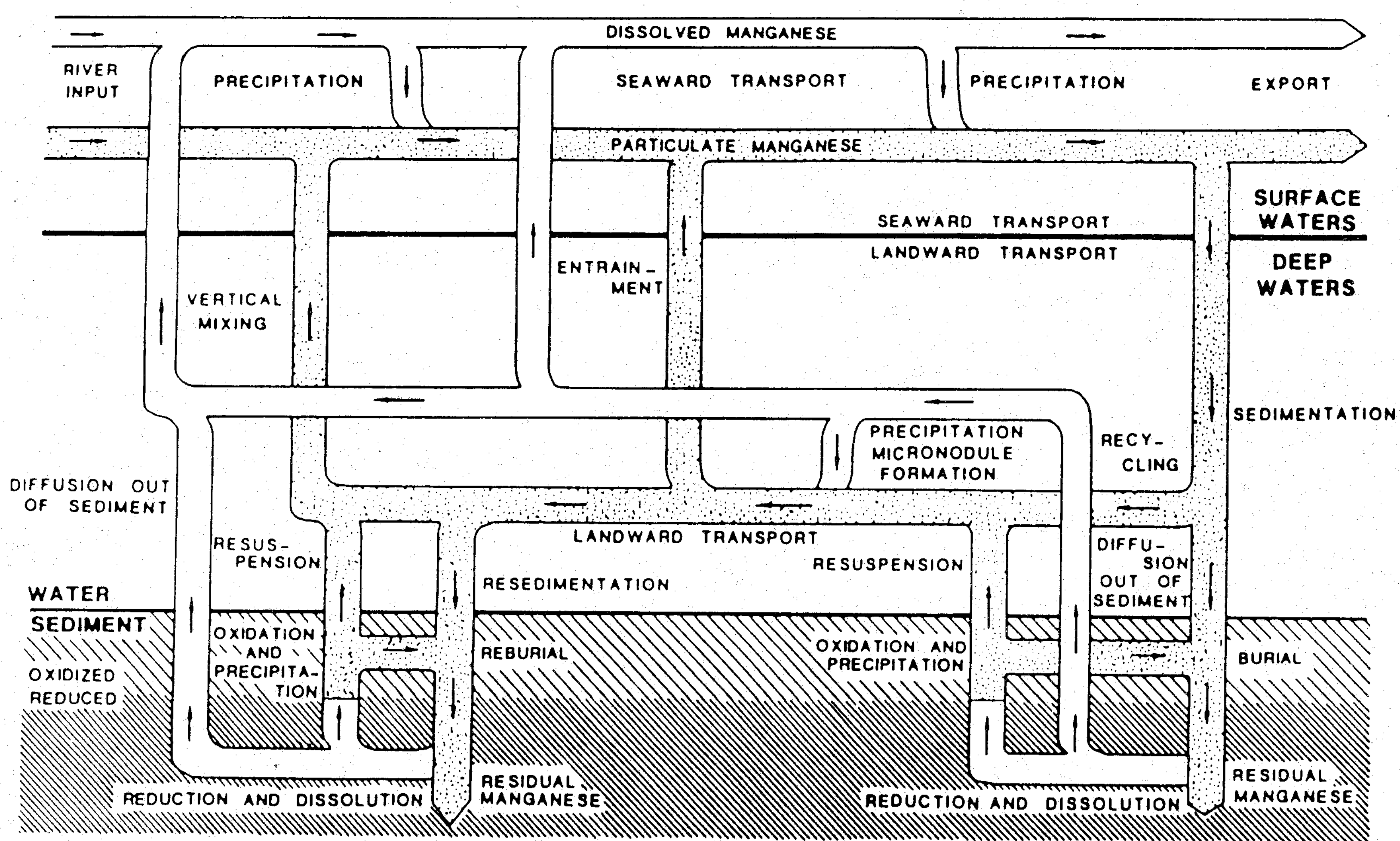


Figure 1.1 A schematic representation of the source/input → sea water internal reactivity → sink/output global journey. The large open arrows indicate transport from material sources, and the large filled arrows indicate transport into material sinks; relative flux magnitudes are not shown. The small arrows indicate only that the strengths of the fluxes can be changed as they cross the various interfaces in the system; thus, g and n represent gross and net inputs or outputs, respectively. Material is brought to the oceans in both particulate and dissolved forms, but is transferred into the major sediment sink mainly as particulate matter. The removal of dissolved material to the sediment sink therefore usually requires its transformation to the particulate phase. This is shown by the p ⇌ d term. However, the intention here is simply to indicate that internal particulate/dissolved reactivity occurs within the seawater reservoir, and it must be stressed that a wide variety of chemical reactions and physicochemical processes are involved in setting the composition of the water phase – see text. For convenience coastal zones are not shown

Source: Reference 29, p. 6.

Figure C-1.—**Fluxes involved in transport of manganese to the oceans.**



Source: Reference 42, p. 222.

Figure C-2.—Schematic model of natural recycling of manganese in the St. Lawrence Estuary.

Commercialization of metal recovery from nodules and/or crusts has been held back by a number of factors. One is capital cost, which for nodule mining generally has been estimated as a minimum of $1 billion for a commercial-size operation. The majority of the cost is associated with processing rather than with mining; one estimate assigns 80% of the capital investment and 75% of operating costs to processing (*50*). A second impediment is the legal barrier posed by the United Nations Law of the Sea Convention, which clouds the terms under which mining of the deep oceans could be conducted in international waters. Legal restrictions can be less forbidding for crust mining and depend only on the national laws applying to an EEZ. A third factor has been uncertainties in metal markets such as those of the 1980's that worked against nodule mining. The mineral economics of copper and nickel are the keys to the economics of a nodule recovery operation. The economics of recovery from crusts depends on the cobalt market (*51*).

Coproduct recovery of manganese, the metal present in greatest amount, has tended to be an optional but not economically critical feature of potential ocean mining projects. Regardless of the economics, mining of nodules and crusts has had an appeal from the strategic viewpoint that such operations have the ability to more than remove the dependence of the United States on foreign sources for supply of cobalt and manganese units.

The near-term outlook for ocean mining is uncertain, according to participants at a workshop on the future of ocean mining held in 1989. The majority of the participants believed that mining of the deep sea would be commercialized in the early part of the 21st century, and the likelihood of nodule mining was assessed as much greater than that for crust mining (*52*). In an OTA study published in 1987, commercial prospects for development of marine minerals were viewed as remote for the foreseeable future, with the possible exceptions of sand and gravel and the precious metals (*53*). OTA placed nodules fourth and crusts fifth in probable order of development on a list of six classes of materials that might be obtained from the EEZ.