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Manganese Availability—Domestic

A Minerals Availability System Appraisal

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PREFACE

The purpose of the Bureau of Mines Minerals Availability Program is to assess the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is part of a continuing series of Minerals Availability System (MAS) reports that analyze the availability of minerals from domestic and foreign sources and the factors that affect availability. Analyses of other minerals are currently in progress. Questions about the MAS program should be addressed to Director, Division of Minerals Availability, Bureau of Mines, 2401 E Street, N.W., Washington, D.C. 20241.

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A Minerals Availability System Appraisal

By Catherine C. Kilgore[1] and Paul R. Thomas[2]

ABSTRACT

The Bureau of Mines investigated the availability of manganese from known domestic occurrences. Eight of these deposits were found to have demonstrated resources totaling 420 million metric tons with an average grade of 10 percent contained manganese. They were found to be submarginally subeconomic.

Economic evaluations of the eight deposits resulted in incentive prices ranging from $8 to almost $35 per long ton unit (22.4 pounds) of contained manganese. Comparing these prices with the current market value of $1.70 per long ton unit of manganese clearly illustrates the submarginal nature of the domestic ores analyzed. These domestic resources would probably not be developed except in the case of an extreme national emergency.

Production from the eight deposits would take 3 to 6 years to develop, and the final product would be manganese ore concentrate, which could be used in the production of ferromanganese. If preproduction development began in 1981, annual production would peak in 1987 with 900,000 metric tons of recoverable manganese. Thereafter, production would see a steady decline unless additional resources were located or technologic improvements were made to allow processing of lower grade material, or unless mining and processing of ocean manganese nodules began to take place.

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INTRODUCTION

The availability of domestic sources of manganese is of vital concern to the United States. Presently, 98 percent of the manganese consumed in this country must be imported; most of the remaining 2 percent is consumed in the form of low-grade manganiferous ore used primarily in iron blast furnaces or to color brick. Manganese is a critical raw material, 90 percent of which is consumed by the steel industry either in the form of ore or as ferroalloys. It is also used as an oxidant for various chemical processes and as a depolarizer for dry cell batteries, and the metal is used to prepare alloys with aluminum and copper.

The purpose of this report is to identify domestic resources and evaluate potential manganese production from these resources. The availability of domestic resources, which might be needed to replace foreign imports during a period of supply interruption, is critical to the formulation of a national minerals policy.

This report expands upon work that was done by the National Materials Advisory Board in their 1976 report on Manganese Recovery Technology (*8*).[3] Their report covered the possible recovery technologies available for the processing of domestic manganese, but it did not deal with the economic availability of domestic resources. Additional work done by the Bureau of Mines on domestic manganese resources and processing has been cited in the bibliography section at the end of this report.

This study looks at the engineering and economic availability of manganese from eight domestic deposits. The names and locations of these deposits are shown in figure 1. The procedure for conducting this study was to identify and define demonstrated manganese resources and the engineering and economic parameters that would affect proposed production from the selected deposits. Capital investments and operating costs for the appropriate mining and beneficiation methods were estimated, and a cost analysis for each deposit was performed. Sensitivity analyses were performed to determine the impact of various parameters, such as the different costs for beneficiation methods and transportation, upon the economic status of each deposit. The impact of State severance taxes and benefits of byproducts, where applicable, were also analyzed.

There has been no manganese ore, concentrate, or nodule containing 35 percent or more manganese produced or shipped within the United States since 1973. However, there are several low-grade domestic deposits that are currently mined for their manganese or combined manganese and iron content. They were not included in the domestic availability analysis because they are used directly either as low-grade feeds to iron blast furnaces or as pigments, and they do not have a price comparable to manganese ore or ferromanganese products currently on the market.

Other manganese resources were excluded from this analysis because the tonnages were inferred rather than demonstrated,[4] or because of technologic problems in producing a marketable product. Domestic deposits excluded from this study include Cuyuna South Range, Emily District, and all but the central southwest portion of the Cuyuna North Range, Minn., Batesville and Mena Districts, Ark., and small deposits in California, Georgia, Montana, Nevada, New Jersey, New Mexico, South Carolina, Tennessee, and Utah.

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[3] Italicized numbers in parentheses refer to items in the list of references preceding the Bibliography.

[4] Figure 2 shows reserve base and inferred reserve base classification categories.

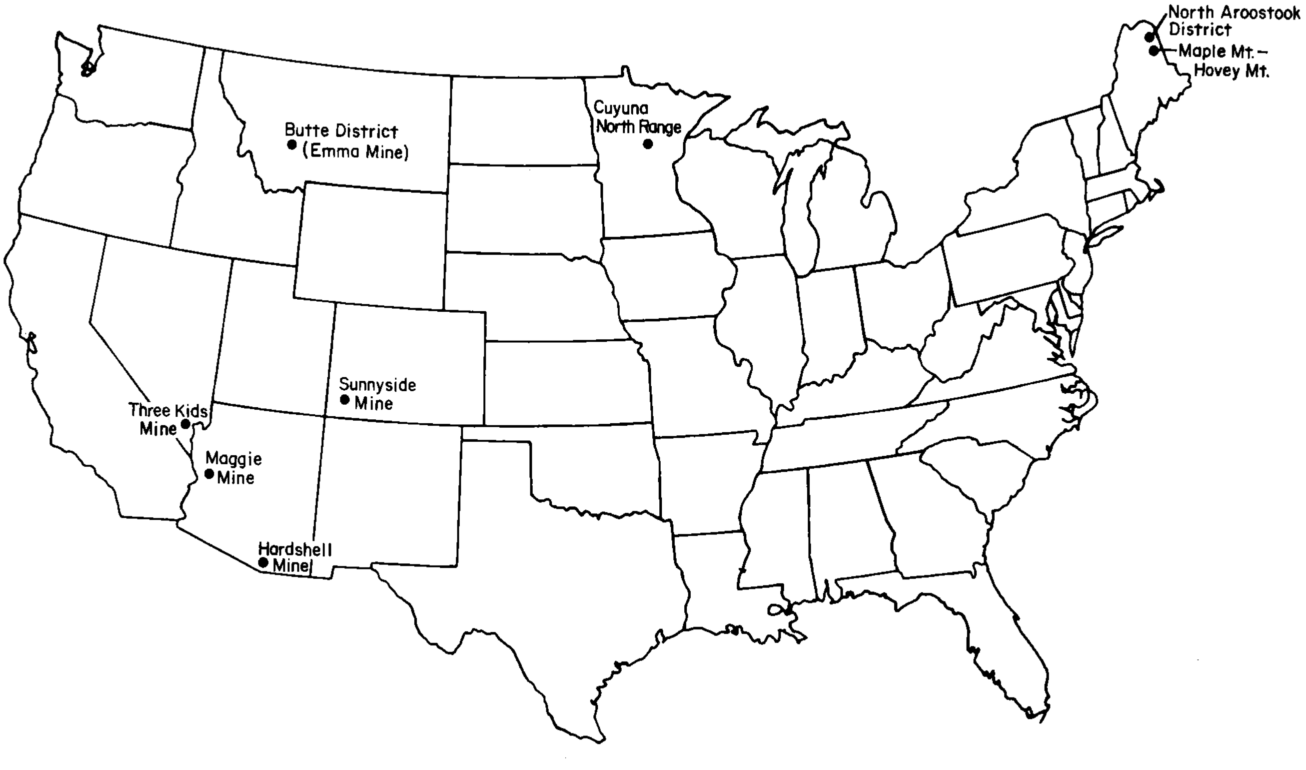

FIGURE 1.—Locations of evaluated domestic manganese resources.

ACKNOWLEDGMENTS

Production and cost data for the deposits analyzed in this study were developed at the Bureau of Mines Field Operations Centers in Denver, Colo., Pittsburgh, Pa., and Spokane, Wash. Further extensive costing, as well as the financial evaluations of the properties, and preparation of this report were performed at the Minerals Availability Field Office in Denver.

ESTIMATION OF DOMESTIC MANGANESE RESOURCES

The reserve base is the in situ portion of demonstrated (measured plus indicated) resources from which reserves are estimated.[5] It includes those resources that are currently economic (reserves) or marginally economic (marginal reserves) and a portion of the subeconomic (resources). For most mineral commodities, the appropriate resource parameters can be specified according to the objectives of the estimators. The position of the lower boundary of the reserve base, which extends into the subeconomic category, is variable depending upon the specified objectives. The reserve base encompasses those portions of the resource that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics.

Selection of deposits for this study was limited to known deposits with demonstrated manganese resources. Because of their subeconomic nature, these deposits were used to establish the available domestic manganese resources, rather than a domestic reserve base. The position of the reserve base within the classification of mineral resources is illustrated in figure 2; the crosshatched portion indicates the approximate location of the domestic manganese resources. The deposits are considered to be submarginal—that portion of subeconomic resources requiring greater than 1.5 times the current price or a major cost-reducing advance in technology in order to be considered for development (*9*).

Eight domestic deposits were selected for analysis in this study (fig. 1). Domestic deposit information and proposed mining and beneficiation data are listed in table 1, and a brief description of each deposit and its products is given in table 2. More detailed descriptions of the deposits can be found in appendix A.

The eight domestic deposits evaluated for this study have total demonstrated resources of almost 420 million metric tons, with an average grade of about 10 percent contained manganese. Resource information for these deposits is given in table 3.

This study is based on current resource estimates, proven and experimental technology, and constant March 1981 prices and costs. As exploration and development yield additional information on grades and tonnages, and as the difference between production costs and market prices changes, portions of the resources may be reclassified. Technologic improvements that enable the mining and processing of lower grade materials and the processing of materials previously considered waste will also have an impact on the economic classification of these resources. However, recent research to develop more cost-effective methods for the beneficiation of low-grade ores has been largely nonproductive. Aside from the increased use of simple upgrading beneficiation methods, chances for a major technological breakthrough in beneficiation methods for low-grade ores are unlikely in the foreseeable future (*9*).

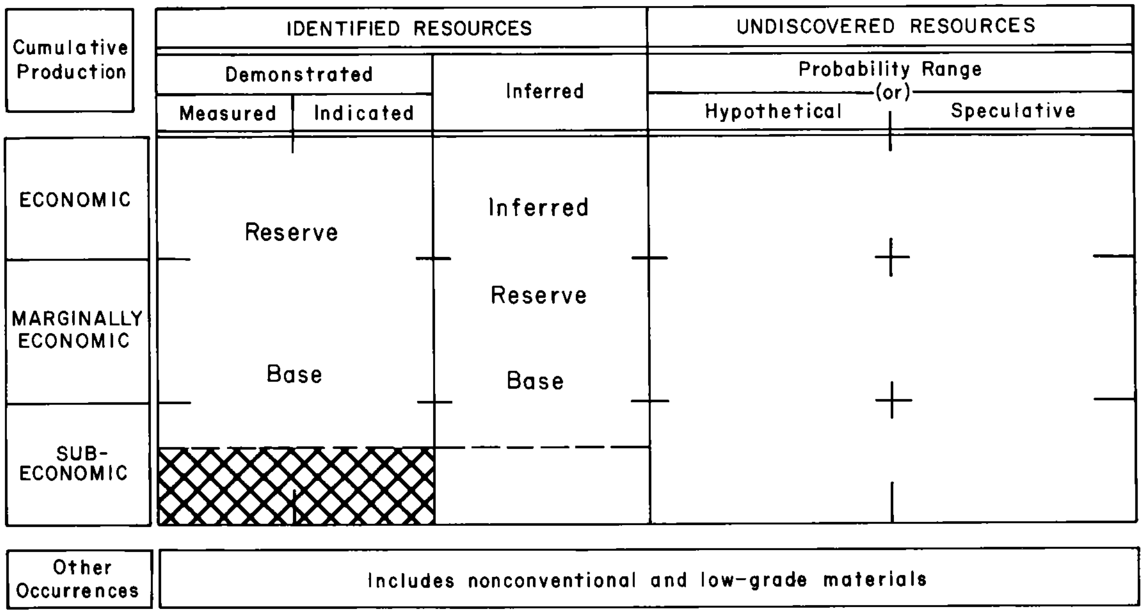

FIGURE 2.—Reserve base and inferred reserve base classification categories. (Crosshatched area indicates position of domestic manganese resources.)

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[5] The reserve base is defined according to the mineral resource-reserve classification system developed jointly by the U.S. Geological Survey and the Bureau of Mines (*13*).

TABLE 1.—Domestic manganese deposit information and proposed mining and milling data[1]

Property name	State	Status of deposit	Minimum lead time, years	Annual capacity, metric tons of ore	Mining method	Beneficiation	
						Method	Status
Hardshell Mine	Arizona	Explored prospect.	4	535,500	Room and pillar.	Leach[2]	Proposed.
Maggie Mine	do	Partially developed.	6	327,900	do	do[2]	Do.
Sunnyside Mine	Colorado	Developed.	4	635,000	Overhand shrink-stoping.	Partial leach.[3]	Do.
Maple Mountain-Hovey Mountain.	Maine	Explored prospect.	6	4,263,000	Open pit.	Leach[2]	Do.
North Aroostook District (Dudley and Gelot Hill).	do	do	6	2,619,900	do	do[2]	Do.
Cuyuna North Range (SW portion).	Minnesota	Past producer.	4	3,570,000	do	do[2]	Proposed, semicommercial; 181 metric tons per day.
Butte District (Emma Mine)	Montana	do	3	400,000	Cut-and-fill stoping.	Flotation[4]	Commercial; 907 metric tons per day.
Three Kids Mine	Nevada	do	3	1,050,000	Open pit.	do[5]	Commercial; 988 metric tons per day.

[1] Further information on proposed mining methods is given in appendix B.
[2] Ammonium carbamate leach process; proposed based on studies of bench-scale tests on Cuyuna North Range ores.
[3] Sunnyside contains a rhodonite-rhodochrosite mineralization. It was proposed that the rhodochrosite portion could be recovered by an ammonium carbamate leach. It is assumed only 50 percent of the manganese is leachable without a quench-leach process.
[4] Bulk sulfide flotation process.
[5] Emulsion flotation process. Past production of manganese has occurred; some changes in this flotation technology may be incorporated for treatment of remaining material.

TABLE 2.—Domestic manganese deposit descriptions[1]

Property name	Major ore minerals	Products	Comments
Hardshell Mine	Pyrolusite, braunite, wad, psilomelane, silver halides.	66.8 pct manganese,[2] silver.	In Harshaw District; worked sporadically on a small scale.
Maggie Mine	Psilomelane, wad, manganite, pyrolusite.	66.8 pct manganese[2]	Located in the Artillery Peak Area. Estimated total identified tonnage of 159 million metric tons; 3.9 pct manganese.
Sunnyside Mine	Rhodonite, rhodochrosite	66.8 pct manganese[2]	To produce from old gold, lead, and zinc workings; total district identified tonnage estimated at 44 million metric tons; 8 pct manganese.
Maple Mountain-Hovey Mountain.	Rhodochrosite, braunite, bementite, rhodonite, spessartite, hematite.	66.8 pct manganese,[2] iron.	Located in central Aroostook District. Forested—environmental factors may be significant.
North Aroostook District (Dudley and Gelot Hill).	Braunite, bementite, manganiferous carbonates, hematite.	66.8 pct manganese,[2] iron.	Area includes 11 additional deposits for a total demonstrated tonnage of 63.9 million metric tons; 9 pct manganese. Agricultural land—environmental factors may be significant.
Cuyuna North Range (SW portion).	Manganiferous limonite, psilomelane, manganite.	66.8 pct manganese,[2] iron.	Resource estimate for 9 deposits in central southwest of North Range; estimated total identified tonnage of North Range is 247 million metric tons; average 8 pct manganese.
Butte District (Emma Mine)	Rhodochrosite, rhodonite, pyrargyrite, sphalerite, tetrahedrite.	47 pct manganese, silver, lead, zinc.	Produced manganese 1917–59. Additional estimated 259,000 metric tons for Travona Mine not included owing to ½-year life.
Three Kids Mine	Wad, psilomelane, pyrolusite.	46 pct manganese	Produced manganese until 1961. Plan to extend old workings; Government stockpiles on site.

[1] Further information on domestic manganese resources is given in appendix A and reference *8*.
[2] This grade is the manganese grade achieved in the semicommercial carbamate leach-processed Cuyuna North Range ores. This grade of agglomerated Mn_3O_4 product would be suitable for ferromanganese production.

TABLE 3.—Domestic manganese resource information

Property name	Grade of contained manganese, percent	Demonstrated resource tonnage, metric tons	Contained manganese, metric tons
Hardshell Mine	15.0	5,895,500	884,325
Maggie Mine	8.75	8,441,000	738,588
Sunnyside Mine	10.0	24,909,000	2,490,900
Maple Mountain-Hovey Mountain	8.87	260,000,000	23,062,000
North Aroostook District (Dudley and Gelot Hill)	9.54	63,100,000	6,109,740
Cuyuna North Range (SW portion)	7.84	48,960,000	3,838,464
Butte District (Emma Mine)	18.0	1,232,000	221,760
Three Kids Mine	13.2	7,230,000	954,360

DOMESTIC MANGANESE DEPOSIT EVALUATIONS

After a deposit was selected for analysis, an evaluation of the property was performed at one of the Bureau of Mines Field Operations Centers, in Denver, Colo., Spokane, Wash., or Pittsburgh, Pa., as well as at the Minerals Availability Field Office in Denver. In order to evaluate the proposed operations, the National Materials Advisory Board (NMAB) report on Manganese Recovery Technology (*8*) was consulted. Using data contained in the NMAB report and current engineering principles, the appropriate mining and beneficiation methods, production rates, and other parameters of production were estimated. For past-producing properties, previous production information was taken into account. Detailed mining information is given in appendix B.

In order to evaluate the economic status of each deposit included in this study, capital and operating costs for mining and beneficiation were derived for the proposed development of each deposit.

CAPITAL AND OPERATING COSTS

Capital expenditures were calculated for exploration, acquisition, development, mine plant and mine equipment, and for constructing and equipping the concentrator. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category that includes costs for access and haulage facilities, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, insurance, and taxes. Environmental costs, except for those included in the design of processing facilities, were not addressed in this analysis.

All acquisition and exploration costs were based on the Field Operation Centers' estimates. The development, mine plant and equipment, and mine operating costs were derived from the Bureau of Mines capital and operating cost estimating system manual (CES) (*1*), as well as from industry sources.

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research. Other costs in the analysis include Federal and State taxes and standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax loss carry-forwards.

BENEFICIATION METHODS AND ASSOCIATED COSTS

The majority of ore consumed in ferromanganese production contains approximately 48 percent manganese. However, in order to achieve an ore concentrate grade that can be used in the production of ferromanganese from low-grade domestic resources, beneficiation methods were employed and a product grade of 66.8 percent manganese was proposed. This higher grade material may result in a "bonus" paid for its higher manganese content per ton, but no such "bonus" has been assumed for this study. The incentive price obtained for all grades was based on a long ton unit (22.4 pounds) of contained manganese. All of the manganese produced for this study has been targeted for consumption as manganese ore by the ferromanganese industry.

Flotation

In 1976, the NMAB (*8*) reviewed the various beneficiation processes available for the recovery of manganese from low-grade domestic deposits. It was concluded in the 1976 study that the simplest, least expensive method of beneficiation was flotation, gravity concentration, and magnetic separation, where applicable. The flotation of some manganese ore has been practiced on a commercial scale. Manganese, Inc., at Henderson, Nev., beneficiated manganiferous material from the Three Kids Mine using an oil-emulsion flotation process followed by nodulizing, from September 1952 until 1961. Anaconda Copper Co., at Anaconda, Mont., beneficiated rhodochrosite ore commercially from the Butte District mines, primarily the Emma Mine, using a bulk sulfide flotation process followed by nodulizing, until 1959.

Beneficiation costs for the oil-emulsion flotation process proposed for the Three Kids Mine and the bulk sulfide flotation process proposed for the Emma Mine were derived in part from the CES. Total beneficiation costs for these two mines also include operating and capital costs scaled from cost data obtained from industry sources for calcining and nodulizing the manganese concentrates. The large amount of diesel fuel required in the emulsion flotation process was also taken into consideration and added to the total beneficiation operating costs required for the Three Kids Mine.

Ammonium Carbamate Leach

The Three Kids and Emma Mines are unique for this study in that they can be beneficiated by gravity and flotation methods. Most of the domestic manganese resources are not amenable to beneficiation by gravity and flotation methods alone. In order to achieve a concentrate suitable for ferromanganese production, additional processing would be necessary. The NMAB recommended the possible combination of beneficiation with hydrometallurgical processes; however, no work as been done on this combination. The NMAB also reviewed the technologic state of the art for smelting processes, vapometallurgy and hydrometallurgy, and concluded that, based upon the level of data to date, the expected costs and adaptability to large-scale production of the sulfur dioxide roast process or the ammonium carbamate leach process were the most viable (*8*).

The sulfur dioxide roast process uses almost twice as much energy as the ammonium carbamate leach process, and energy costs have increased more than any other cost since the 1976 report was published. Thus, for this study, the ammonium carbamate leach process was chosen over the sulfur dioxide roast process for beneficiation of the Sunnyside Mine, Cuyuna North Range, Maggie Mine, Hardshell Mine, Maple Mountain-Hovey Mountain, and Northern Aroostook District manganese-bearing materials. Manganese Chemicals Corp., at Riverton, Minn., beneficiated the Cuyuna Range manganiferous protore in a semicommercial plant using the ammonium carbamate leach process, from 1953 until early 1962. The process has been studied on a laboratory scale for treating ores from the Three Kids and Maggie Mines, as well. The Riverton plant did not recover an iron concentrate from the leach residues; however, iron recovery has been proven feasible on a small batch scale by the Bureau of Mines.

The beneficiation operating and capital costs for the ammonium carbamate leach process proposed for the remaining mines were determined by updating and scaling the costs given in the 1976 NMAB report (*8*). Additional capital costs for grinding, magnetic separation of iron,

TABLE 4.—Typical capital and operating costs for domestic manganese operations[1]

Operation[2]	Thousand metric tons processed per year	Capital costs, per annual metric ton ore	Operating costs, per annual metric ton ore
Mine:			
Open pit	1,000-4,500	$ 4.00-$ 13.00	$ 2.00-$ 6.00
Underground	300- 650	6.00- 40.00	16.00- 24.00
Mill:			
Flotation	400-1,000	30.00- 55.00	20.00- 33.00
Ammonium carbamate leach	300- 650	290.00- 370.00	25.00- 30.00
Do	2,500-4,500	140.00- 205.00	24.00- 27.00

[1] Costs in March 1981 dollars.
[2] Mining and milling operations proposed for each deposit are listed in table 1.

concentrating, and pelletizing, as well as the operating costs for recovering pelletized iron concentrates for the Maple Mountain-Hovey Mountain, North Aroostook District, and Cuyuna North Range manganese ores, were based on cost data obtained from industry sources. The ranges of capital and operating costs for developing proposed domestic manganese deposits are shown in table 4.

ECONOMIC ANALYSIS

The Minerals Availability System (MAS) is a continuously evolving methodology for the analysis of longrun mineral resource availability. An integral part of this system is the Supply Analysis Model (SAM) (*2*) developed by personnel of the Bureau of Mines Minerals Availability Field Office. This interactive computer system is an effective mathematical tool for analyzing the effects of various parameters upon the economic availability of domestic and international resources.

After the production parameters and costs for the development of domestic manganese deposits were established, the SAM was used to perform various economic analyses pertaining to the availability of domestic manganese. The SAM system is a comprehensive economic analysis simulator that is used to determine the price of the primary commodity required to obtain a specified discounted cash flow rate of return (DCFROR). The DCFROR is defined as the rate that makes the present value of all future revenues equal to the present value of all future costs.

For this study, a minimum rate of return of 15 percent was specified when determining a nonproducing property's incentive price for the primary commodity manganese ore. An incentive price is the price at which a firm would be willing to produce the commodity, over the life of the operation, and at which it would recover full costs, including a 15-percent rate of return on total investments. This rate was considered the minimum sufficient to attract new capital to the industry.

The SAM system contains a separate tax records file for each State, which includes all the relevant tax parameters under which a mining firm would operate. These tax parameters are applied to each mineral deposit under evaluation, with the implicit assumption that each deposit represents a separate corporate entity. In addition, the tax calculation routine allows for the varying of these parameters and calculations, in order to ascertain what effect differing State severance taxes have upon the determination of the incentive price required for the primary commodity.

Price tables are maintained for all commodities, byproducts, and coproducts that will be relevant to the availability analyses, and all byproducts recovered in the analyses are considered to be marketable. The SAM system also contains a separate file of economic indexes to allow for continuous updating of all cost estimates for both producing and nonproducing deposits. The byproduct prices used in this study are shown in table 5.

Using the SAM system, detailed cash flow analyses are generated for each preproduction and production year of a deposit, beginning with the first year of analysis. The initial year of analysis for this study was 1981. Upon completion of the individual analyses, all properties that had been identified for inclusion in the study were simultaneously analyzed and aggregated onto an availability curve. This curve is a tonnage-price relationship that shows the recoverable product available at determined longrun prices and given rates of return. It is an aggregation of total production potential that would eventuate over the entire producing life of each deposit at its average total cost of production. For this study, annual availability curves were constructed to account for the time lags involved in achieving the total production potential. These curves are simply the total availability of domestic manganese disaggregated on a yearly basis.

TABLE 5.—Commodity prices used in the economic analyses

Commodity	*Price, March 1981*
Cobalt	$20.00 per pound
Copper	.87 per pound
Iron	80.50 per metric ton pellets
Lead	.35 per pound
Nickel	3.45 per pound
Silver	12.34 per troy ounce
Zinc	.41 per pound

Source: Reference *11*.

Certain assumptions are inherent in these curves. First, all deposits produce at full operating capacity throughout the productive life of the deposit. Second, each operation is able to sell all of its output at the determined price[6] and obtain at least the minimum specified rate of return. Third, all preproduction development of each deposit began in January 1981.

Additional assumptions incorporated in this study were based upon the need to determine the potential availability of domestic manganese under an emergency situation. As a result, the additional time lags and potential costs involved in filing environmental impact statements, receiving required permits, financing, etc., have not been included in the analyses. The preproduction period allows only for the minumum engineering and construction period necessary to initiate production under the proposed development plan.

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[6] Since price equals average total cost (which includes an assumed normal rate of return), the price-cost differential equals zero and there are no abnormal profits in an economic sense.

DOMESTIC DEMAND AND IMPORT DEPENDENCE

Current demand in the United States for all forms of manganese is approximately 1.4 million metric tons, with an expected annual growth rate of 1.6 percent annually through the year 2000 (*4*). Since presently there are no suitable substitutes for manganese in the iron and steel industries, demand and, subsequently, prices for manganese are dependent upon steel production levels. Worldwide demand for manganese is expected to increase substantially in the future, and it is important that the United States secure a reliable source of manganese to avoid supply interruptions.

As of March 1981, imported metallurgical manganese ore averaging 46 to 48 percent manganese continued to be quoted in the 1980 price range of $1.66 to $1.75 per long ton unit contained manganese, delivered to Pittsburgh or Chicago. Standard high-carbon ferromanganese with 78 percent contained manganese, produced in the United States, had list prices of $490 and $530 per long ton of alloy, while foreign-produced ferromanganese imported to Pittsburgh or Chicago was quoted as selling between $390 and $425 per long ton of alloy (*5*).

The United States has become increasingly more dependent upon ferromanganese imports over the last decade as the major ore-producing countries have increased their ferromanganese capacities to take advantage of the additional value added in their exports. Transportation costs favor production of ferromanganese near the source of ore, and the rising costs of labor, capital, energy, and pollution control in the United States have also encouraged increased ferromanganese imports (*9*).

The shift to ferromanganese imports versus ore imports during the 1970's is shown on table 6. This table indicates that during the last decade the percentage of imports of ferromanganese to this country has increased, while the percentage of manganese ore imports has declined (*3*). In 1980, the United States imported approximately 41 percent of its manganese in the form of manganese ore with a minimum grade of 35 percent contained manganese (*10*). Most of the ore originated in Australia, South Africa, and Gabon. The remaining 59 percent of the manganese imported was mainly from South Africa and France in the form of ferromanganese, which is the final product of the majority of ore shipped to this country. For this study, the product of the proposed domestic operations, ore concentrate, is targeted to replace only losses in the U.S. supply of manganese ore, not losses in ferromanganese.

If the United States were to develop the proposed domestic operations, sufficient domestic refinery capacity would have to be maintained in order to process the domestic ores to ferromanganese. The shift away from importing ore has resulted in the reduction of our ability to produce ferromanganese domestically in the volume that would be required to support steel production, and this, together with rising costs, has made the United States more dependent upon foreign sources of ferromanganese.

Table 7 outlines the current status of the Government stockpile for manganese, and, as the table indicates, the majority of the manganese in the stockpile is in the form of metallurgical grade ore. Table 8 shows the statistics for manganese consumer and producer stocks and consumption levels for 1980 and 1981. Current Government and industry stocks of metallurgical grade ore total 2,974,000 metric tons. With the present annual consumption of manganese ore estimated at 975,000 metric tons, present stockpiled supplies would last approximately 3 years. The stockpiled manganese ore, which would be used primarily for the production of ferromanganese during a period of supply interruption, would require adequate ferromanganese processing capacity in order to be utilized for domestic production and consumption.

Rising costs, particularly in the energy-intensive pollution control systems required for the domestic ferroalloy plants, have resulted in the divestiture of a number of plants owned by U.S. companies. Although the U.S. companies have found the ferroalloy plants not to be cost effective, certain foreign ferroalloy companies have discovered that the U.S.-based plants are advantageous for the production of ferromanganese aimed at U.S. markets.

TABLE 6.—U.S. imports of manganese ore and ferromanganese, 1970–80

Year	Ore imported				Ferromanganese imported			
	Total		Mn content		Total		Mn content	
	metric tons	pct[1]	metric tons	pct[2]	metric tons	pct[3]	metric tons	pct[4]
1970	1,573,695	79.2	767,962	48.8	263,888	20.8	201,870	78.0
1971	1,736,237	83.2	850,877	49.0	220,200	16.8	171,659	78.0
1972	1,469,569	74.3	718,974	48.9	316,125	25.7	249,168	78.8
1973	1,369,382	70.4	655,635	47.9	354,063	29.6	275,607	77.8
1974	1,111,105	64.4	537,686	48.4	382,048	35.6	297,382	77.8
1975	1,427,659	70.0	694,336	48.6	360,271	30.0	278,132	77.2
1976	1,194,348	60.9	588,865	49.3	487,430	39.1	378,612	77.7
1977	844,369	52.2	411,985	48.8	484,722	47.8	377,385	77.9
1978	496,873	34.4	252,338	50.8	617,122	65.6	481,795	78.1
1979	453,302	27.6	220,903	48.7	744,840	72.4	579,332	77.8
1980	628,512	41.1	300,352	47.8	550,434	58.9	430,259	78.2

[1] Percent of total U.S. imports (ore and ferromanganese) attributed to ore.

[2] Percent manganese contained in total gross weight of imported ore.

[3] Percent of total U.S. imports (ore and ferromanganese) attributed to ferromanganese.

[4] Percent manganese contained in total gross weight of imported ferromanganese.

Source: References *3* and *10*.

TABLE 7.—Government stockpile for manganese, status as of November 30, 1981

(Thousand metric tons)

Material	Goal	Total inventory[1]	Authorized for disposal	Sales, 11 months
Battery:				
Natural ore	56	168	41	9
Synthetic dioxide	23	3	0	0
Chemical ore	154	200	46	0
Metallurgical ore	2,450	2,185	0	0
Ferromanganese:				
High carbon	398	544	0	0
Medium carbon	0	26	0	0
Silicomanganese	0	22	0	0
Electrolytic metal	0	13	0	0

[1] In addition to data shown, the stockpile contains 30,838 metric tons of natural battery ore and 871,627 metric tons of metallurgical ore, both of nonstockpile grade.

Source: Reference *7*.

TABLE 8.—Manganese stocks and consumption for 1980 and 1981

Statistics	1980	1981e
Producer and consumer stocks, thousand metric tons:		
Manganese ore[1]	934	789
Ferromanganese[2]	187	150
Shipments from Government stockpile, thousand metric tons:		
Manganese ore[1]	332	286
Ferromanganese[2]	0	0
Consumption, thousand metric tons:		
Reported consumption:[3]		
Manganese ore[1]	970	975
Ferromanganese[2]	716	803
Apparent consumption of manganese[4]	933	1,043
Net import reliance as a percentage of apparent consumption[5]	98	98

e Estimated.

[1] Manganese ore ranging from 35 to 54 percent manganese content.

[2] Ferromanganese ranging from 74 to 95 percent manganese content.

[3] Sum of manganese ore consumption and ferromanganese consumption cannot be used as total consumption, because much of the ore is consumed to produce ferromanganese.

[4] Thousand metric tons, manganese content (elemental manganese). Based on estimates of average content for all significant components except imports, which are reported content.

[5] Net import reliance = imports − exports + adjustments for Government and industry stock changes.

Source: Reference *7*.

A consortium headed by Elkem-Spigerverket of Norway has purchased most of Union Carbide's ferroalloy division. Another Norwegian consortium has recently signed a letter of intent to purchase ferroalloy plants owned by Ohio Ferro-Alloys. The Norwegian interest in U.S. plants has been encouraged by inflated energy costs and the limited availability of power in that country. Norway exports the majority of its ferroalloy products, and inflated freight costs also make it worthwhile to have a U.S. production base (*6*).

Other domestic manganese ferroalloy plants have been purchased by companies from Mexico, South Africa, Belgium, and the Federal Republic of Germany (*3*). This recent trend of purchases of domestic ferroalloy capacity by foreign companies has greatly reduced our ability to control production of ferromanganese domestically. Without an adequate ferromanganese processing capacity, a diversified or secure source of ore, even in the Government stockpile, may not protect the United States from supply interruptions under normal circumstances. Of course, in the event of a national emergency, the Federal Government could assume control of plants physically located in the United States to the extent that national security required it. Also, in an emergency, limited quantities of ferromanganese could be produced in small blast furnaces, if necessary.

AVAILABILITY OF DOMESTIC MANGANESE

Many factors contribute to the economic status of a deposit. Capital expenditures vary from deposit to deposit depending upon the mining and milling methods used, as well as the annual capacity. Transportation distances and the recovery of byproducts also impact upon the incentive price. Although the major costs for developing the deposits are in the mill capital and operating costs, future improvements in beneficiation processes appear unlikely. Cost reductions in this area would be the most effective means of improving the overall economic availability of domestic manganese (*9*).

LAND-BASED DEPOSITS

Economic evaluations of the eight domestic deposits resulted in incentive prices ranging from $8 to almost $35 per long ton unit of contained manganese. Comparing these prices with the current market value of $1.70 per long ton unit for manganese clearly illustrates the submarginal nature of the domestic ores analyzed. Economically viable production from these deposits could not take place without a possible Government subsidization plan or a major cost-reducing advance in technology, or both.

The annual potential production curve in figure 3 illustrates the cumulative tonnages that would be available at specific prices for the selected years 1985, 1987, and 1990. Under the assumptions made for this study, with preproduction construction beginning in 1981, production would peak in 1987 and then begin to decline. This rapid peak and decline in production is best illustrated in the time-tonnage relationship shown in figure 4. The price range of $0 to $35 per long ton unit of manganese includes all potential production available from the current domestic resources identified in this study. Potential annual domestic production

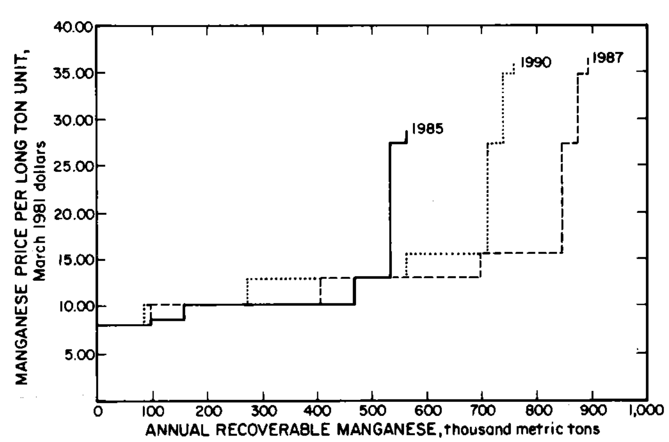

FIGURE 3.—Annual production of domestic manganese for selected years at various prices.

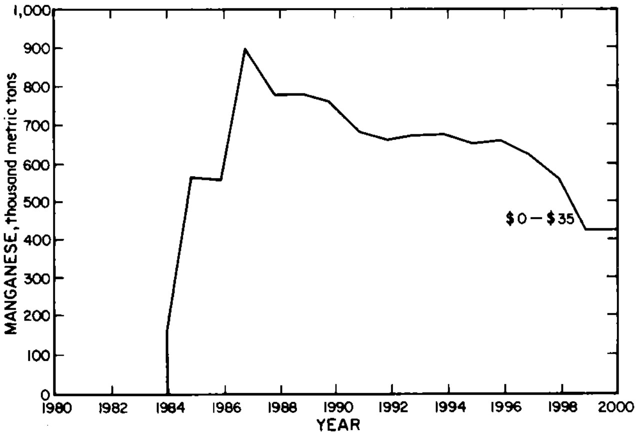

FIGURE 4.—Annual production of domestic manganese through the year 2000, priced below $35 per long ton unit, in March 1981 dollars.

peaks at about 900,000 metric tons of recoverable manganese in 1987. Thereafter, production steadily declines as resources become depleted and the grades of the remaining producing deposits become lower.

Future production would depend upon technologic improvements that would allow for processing of even lower grade materials, and/or upon the availability of additional resources from known sources, such as ocean nodules, and currently undiscovered resources. The mining and processing of deep sea nodules could begin to replace diminishing land-based resources by the early 1990's (*9*).

MANGANESE NODULES AS AN ALTERNATIVE RESOURCE

Deep sea nodules of the North Pacific have an estimated 16.3 billion metric tons of contained manganese and could be one potential manganese resource available to the United States. The assay values for the Pacific nodules include manganese, 25 percent, iron, 5 percent, nickel, 1.4 percent, copper, 1.2 percent, and cobalt, 0.2 percent (*12*).

Recent U.S. legislation (Public Law 96-283)[7] authorizing the National Oceanic and Atmospheric Administration (U.S. Department of Commerce) to start issuing exploration licenses to companies incorporated in the United States should help to stimulate renewed interest in recovering the nodules. The law prohibits mining until 1988 in order to give the Law of the Sea treaty time to be ratified.

Preliminary economic evaluations by the Bureau of Mines for the recovery of nodules from one of the more promising sites in the North Pacific shows that the nodules are presently submarginally subeconomic. However, the analysis indicates that, because of the high assay values and subsequent byproduct credits, the recovery of manganese from nodules would probably require a lower incentive price than any of the land-based deposits included in this report. It has been estimated that capital investments for a typical ocean-mining project recovering and processing approximately 1 million metric tons of nodules per year would require $600 to $700 million today, with operating costs for the recovery of manganese, copper, nickel, and cobalt estimated at approximately $125 per ton of nodules. The capital investments included will only cover the costs required to bring the deposit online. All costs previous to preproduction construction were considered to be sunk.

Numerous uncertainties are deterrents to investment in ocean mining. The large financial exposure in a high-risk venture, unsolved legal problems relating to security of tenure at an ocean-mining site, and the absence of requisite tax policies all combine to discourage ocean-mining operations (*5*). Commercial mining of the North Pacific ocean nodules as an alternative to U.S. import dependence is probably at least 10 years away, assuming there are no undue delays in acquiring environmental permits for operations at sea and for processing on land (*5, 9*).

Manganese pavement and nodules of the Blake Plateau are located on the Outer Continental Shelf (OCS), off the coast of South Carolina. These occurrences are not under the jurisdiction of the Deep Seabed Hard Minerals Resources Act because they occur within the exclusive economic zone of the United States. Development of the Blake Plateau resources would be controlled by the OCS Hard Minerals Leasing Program, which is presently in the planning stages (*12*).

The Blake Plateau deposits occur at much shallower depths (600-1,000 meters) than do the nodules of the North Pacific (3,000-5,000 meters), and they have an estimated tonnage of 250 million metric tons, with approximately 37.5 million metric tons of contained manganese. The assay values of the pavement and nodules include manganese, 15 percent, iron, 12 percent, nickel, 0.45 percent, copper, 0.1 percent, and cobalt, 0.3 percent. The nodules also contain an average of 0.5 parts per million platinum (*12*).

Recent technology research indicates that the nodules may be suitable for petroleum catalyst applications with relatively little processing. After the nodules are used as a catalyst, the metal values could be recovered from the spent material. Although the Blake Plateau nodules have been considered to be submarginally subeconomic, the recent interest in potential multiple uses for the nodules has improved the economic outlook for recovery (*12*). The establishment of an OCS hard minerals leasing program, along with an improved economic outlook, could potentially make recovery of the Blake Plateau resources a viable source of manganese for the United States.

SENSITIVITY ANALYSES

The following sections discuss the sensitivity analyses that were performed to isolate the impact of different variables upon the economic availability of domestic manganese.

IMPACT OF BENEFICIATION COSTS

To analyze the extent of the economic impact of beneficiation methods upon the availability of domestic manganese resources, the Three Kids Mine was evaluated using both the oil-emulsion flotation method and the ammonium carbamate leach process. Beneficiation by the leach process required an incentive price 1.8 times greater than that required for the emulsion flotation. The leach beneficiation process proposed for the majority of the deposits in this study was found to be a major contributing factor to the submarginal, subeconomic nature of the deposits.

Cost reductions in beneficiation methods are based upon technologic improvements, and a breakthrough would be the single most significant factor for improving the economic status of the domestic deposits analyzed. However, even reducing the incentive price for manganese by a factor of 1.8 does not bring any of the domestic properties within the range of present market values.

IMPACT OF TRANSPORTATION COSTS

Transportation was determined to be another major factor impacting the incentive price for the production of domestic manganese. Rail shipping costs from the mill to market were estimated for the manganese concentrates from all of the mines, except the concentrate from the Cuyuna North Range, which was delivered to Pittsburgh via barge. The differences in the required incentive prices for the eight mines evaluated are shown in table 9. Most of the deposits are a long distance from the market at Pittsburgh, and the amount of change that this causes in the incentive price is substantial compared with the present market value of manganese. In two cases, increases in the incentive price indicate that the cost of transportation exceeds the present average market price of $1.70 per long ton unit of contained

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[7] Public Law 96-283 is the Deep Seabed Hard Minerals Resources Act, which was passed on June 28, 1980. Its purpose was to establish interim procedures for ocean resource development. The law can be overruled by a final treaty from the United Nations Conference on the Law of the Sea.

TABLE 9.—Impact of transportation costs on the incentive prices for domestic manganese

Property name	Approximate distance,[1] miles	Change in incentive price[2]
Cuyuna North Range	550	+$0.02
Maple Mountain-Hovey Mountain	900	+ .81
North Aroostook District	1,000	+ .92
Sunnyside Mine	1,500	+ 1.22
Maggie Mine	1,900	+ 1.35
Hardshell Mine	1,850	+ 1.55
Three Kids Mine	1,900	+ 2.17
Butte District	1,900	+ 2.38

[1] All transportation is by rail from site to Pittsburgh, Pa., except from Cuyuna North Range, which is by barge.

[2] Per long ton unit.

manganese. Transportation costs will have to be reduced or compensated for in some manner if most of these deposits are to be considered for production.

IMPACT OF CHANGES IN BYPRODUCT PRICES

The presence of byproducts enhances the economic availability of manganese. In order to show the impact of changes in byproduct prices, a sensitivity analysis was performed substituting March 1980 prices for the study value prices of March 1981. The analysis was done in March 1981 costs to avoid the influences of inflation, and March 1980 prices were used because they represent the probable high or low price fluctuations, without being extreme. As illustrated in table 10, the required incentive price for manganese fluctuates with changes in byproduct commodity prices. For example, as the price of silver dropped from $24.13 per troy ounce in March 1980 to $12.34 per troy ounce in March 1981, the associated incentive price for manganese from the Hardshell Mine rose 27.5 percent.

In order to ascertain the total amount of change in the incentive price caused by a byproduct, Maple Mountain-Hovey Mountain Mine was evaluated both with and without an iron byproduct. The benefit of the iron byproduct lowered the required incentive price for manganese by 9.2 percent. It should be noted that the actual amount of change in the incentive price owing to byproducts is dependent not only upon price, but upon the grade and amount of the byproduct, as well as its marketability.

The Hardshell Mine was the most sensitive to byproduct price changes because of the high amount of silver recovered. In properties with potential byproduct recovery, increased prices for those byproducts may spark an interest in their recovery, but, unless manganese prices also rise dramatically, manganese recovery could still be uneconomical. High byproduct prices may help to lower the incentive price for domestic manganese; however, none of the properties analyzed in this study became competitively priced with reasonable increases in byproduct prices.

TABLE 10.—Changes in manganese incentive prices as a result of changes in byproduct prices from March 1980 to March 1981

Property name	Byproduct to manganese				Change in manganese incentive price,[1] percent
	Type	Price			
		Per	March 1980	March 1981	
Hardshell Mine	Silver	Troy ounce	$24.13	$12.34	+27.5
Butte District	do	do	24.13	12.34	[2]+ 4.2
	Lead	Pound	.49	.35	
	Zinc	do	.38	.41	
North Aroostook District.	Iron	Metric ton	73.66	80.50	− 1.6
Maple Mountain-Hovey Mountain.	do	do	73.66	80.50	− 2.1
Cuyuna North Range.	do	do	73.66	80.50	− 4.1

[1] Price equals average total cost and includes byproduct credits. Analysis done in March 1981 dollars.

[2] Change of +4.2 percent for Butte District (Emma Mine) includes revenues generated by the three byproducts: silver, lead, and zinc.

IMPACT OF STATE SEVERANCE TAXES

In order to assess the impact of differing State severance taxes upon the economic availability of domestic manganese, a typical property was developed and evaluated under each State's tax system. This hypothetical property was developed assuming a 20-year production life, with 4 years of preproduction, and a final product grade of 66.8 percent manganese with no byproducts. Because of the large impact of transportation costs upon the incentive price, an average transportation distance of 1,450 miles by rail from the site to the market was assumed.

The severance taxes applied within each State are given in table 11. Because Maine assessed no severance tax at the time of this study, it was used as a base case to determine the percentage of change in the incentive price owing to severance taxes. The current State severance tax rates and points of incidence were employed, except in Minnesota, which has had no recent commercial manganese ore (35 percent or more manganese) production and does not presently have a tax on manganese. The severance tax rate assumed for all of the Minnesota analyses was the iron ore occupation tax. This tax would be applied to any byproduct iron, and it was assumed that a tax on manganese would be similar.

There was a 12-percent range in the incentive price for manganese from the hypothetical property when it was evaluated within each of the six State tax systems. It can be seen in table 11 that, generally, as the total amount of severance tax paid in undiscounted dollars increases, the magnitude of change in the incentive price also increases. Because of its lack of State income and property taxes, Minnesota was the one exception, where the high amount of severance taxes paid was not clearly reflected in the change in incentive price. It should be noted that, as in the case of Minnesota, the other taxes applied to the property also have an impact upon the price.

TABLE 11.—Changes in incentive prices for manganese as a result of differing State severance taxes

State	Severance tax			Change in incentive price,[2] percent
	Tax paid[1] (millions)	Tax rate, percent	Point of incidence	
Maine	0	0	None	0
Nevada	$10.5	1.3	Net proceeds[3]	+ 1.0
Colorado	28.8	2.25	Value after mining[4]	+ 5.5
Montana	30.8	.5	do.[4]	+ 5.7
Arizona	43.6	2.5	Value after milling[5]	+12.0
Minnesota	200.8	15.0	Value after mining[4]	+ 8.5

[1] Total amount of tax paid over the 20-year producing life of the hypothetical property in undiscounted dollars.

[2] Maine was used as a base for determining percentage changes in incentive price because it assessed no severance tax at the time of this study.

[3] Net proceeds tax is a sliding scale tax assessed on before-tax income less all operating and transportation costs, depreciation, interest, expensed exploration and development, property tax, and royalties.

[4] Tax based on the value of the commodity after mining. The tax is assessed on the gross revenues of the commodity less the smelter and refinery operating costs, mill-to-smelter and smelter-to-refinery transportation, and the percentage of the total mill operating costs assigned to the commodity times the total mill operating costs.

[5] Tax based on the value of the commodity after milling. The tax is assessed on the gross revenues of the commodity less the smelter operating costs, refinery operating costs, and smelter to refinery transportation costs.

CONCLUSIONS

The eight domestic manganese deposits evaluated by the Bureau of Mines have total demonstrated resources of 420 million metric tons with an average grade of 10 percent contained manganese. These deposits were found to be submarginally subeconomic, requiring greater than 1.5 times the current price or a major cost-reducing advance in technology in order to be considered for development. The possibility of a major technologic breakthrough appears unlikely at the present time, and these eight domestic deposits would probably not be developed except in the case of an extreme national emergency.

The sensitivity analyses performed indicated that beneficiation costs were a major contributing factor to the economic status of a deposit. Improvements in this area would be the most effective means of reducing the cost of production. Transportation costs also had a large impact upon the incentive price for manganese. For several properties, the transportation costs alone were greater than the present market value of $1.70 per long ton unit of contained manganese. Byproducts and byproduct prices improved the economics of a deposit, but even with reasonable increases in byproduct prices none of the domestic deposits become economically viable. State severance taxes have some impact upon the economics, with a 12-percent range in the incentive price found among the six States involved in the study.

Annual production of domestic ore would peak at 900,000 metric tons of recoverable manganese in 1987 if preproduction development began in 1981. Production from the domestic deposits evaluated in this study would be consumed as manganese ore for the production of ferromanganese. Current annual consumption of manganese ore in the United States is approximately 975,000 metric tons. Given this consumption rate, production from domestic ores would not meet current demand. Even with the 3-year supply of stockpiled metallurgical-grade ore, adequate ferromanganese processing capacity would be required to process manganese ore to the final product, ferromanganese.

Deep sea nodules of the North Pacific are a vast potential manganese resource available to the United States. Recent U.S. legislation empowering the Commerce Department to start issuing mining licenses to companies incorporated in the United States should help renew interest in recovering the nodules, which contain an estimated 16.3 billion metric tons of manganese. However, with the legal and financial uncertainties surrounding this vast resource, actual development is probably still 10 years away (*9*).

Manganese pavement and nodules containing approximately 37.5 million metric tons of manganese occur on the Blake Plateau off the coast of South Carolina, within the exclusive economic zone of the United States. Development would be controlled by an Outer Continental Shelf Hard Minerals Leasing Program, which is presently in the planning stages. Although presently considered to be submarginally subeconomic, recent technology research indicates that the nodules may be suitable for catalyst applications with relatively little processing, and that the metal values present could be recovered after the material had been spent.

In recent years, the United States has begun to import less manganese ore and more ferromanganese. This trend has been encouraged by rising costs, particularly energy and transportation costs, and by the ore-producing countries, which are looking for the increased value added in their exports. In turn, this trend has reduced domestic ferromanganese production capacity. Reducing our production capacity has severely limited our ability to protect domestic industries from supply interruptions, and has made the United States more dependent upon foreign sources of ferromanganese.

REFERENCES

1. Clement, G. K., Jr., R. L. Miller, P. A. Seibert, L. Avery, and H. Bennett. Capital and Operating Cost Estimating System Manual for Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. BuMines Special Pub., 1980, 149 pp.

Also available as:

STRAAM Engineers, Inc. Capital and Operating Cost Estimating System Handbook—Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. Submitted to the Bureau of Mines under contract J0255026, 1977, rev. 1978 and 1979, 374 pp.; available from the Minerals Availability Field Office, Bureau of Mines, Denver, Colo.

2. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1980, 45 pp.

3. DeHuff, G. L. Manganese. BuMines Minerals Yearbooks, 1970-79.

4. DeHuff, G. L., and T. S. Jones. Manganese. BuMines Mineral Commodity Profile, 1979, 19 pp.

5. Engineering and Mining Journal. Manganese, Slack Steel Industry Cools 1981 Price Outlook. V. 182, March 1981, pp. 117-121.

6. ——. Norwegians Eye More U.S. Ferroalloy Plants. V. 182, July 1981, p. 19.

7. Jones, T. S. Manganese. Sec. in BuMines Mineral Commodity Summaries 1982. Pp. 94-95.

8. National Materials Advisory Board. Manganese Recovery Technology. National Academy of Sciences, Washington, D.C., NMAB-323, 1976, 94 pp.

9. ——. Manganese Reserves and Resources of the World and Their Industrial Implications. National Academy of Sciences, Washington, D.C., NMAB-374, 1981, 360 pp.

10. U.S. Bureau of Mines. Manganese (Monthly). Mineral Industry Surveys, January 1980 through May 1981.

11. ——. Minerals and Materials—A Monthly Survey. Commodity Tables, April 1981.

12. U.S. Department of the Interior. Program Feasibility Study. OCS Hard Minerals Leasing. Summary document, August 1979, 180 pp.; NTIS PB 81-192551.

13. U.S. Geological Survey and U.S. Bureau of Mines. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Survey Circ. 831, 1980, 5 pp.

BIBLIOGRAPHY

1. Allen, G. L., and others. Utilization of Three Kids Manganese Ore in the Production of Electrolytic Manganese. BuMines RI 3815, 1945, 78 pp.

2. Beltrame, R. J., R. C. Holtzman, and T. E. Wahl. Manganese Resources of the Cuyuna Range. East-Central Minnesota Geol. Survey RI 24, 1981, 22 pp.

3. Dean, R. S., F. D. DeVaney, and W. H. Coghill. Manganese: Its Occurrence, Milling, and Metallurgy. Part I. BuMines IC 6768, 1934, 98 pp.

4. Eilertsen, N. A. Maple Mountain-Hovey Mountain Manganese Project, Central District, Aroostook County, Maine. BuMines RI 4921, 1952, 118 pp.

5. Johnson, A. C., and R. R. Trengove. The Three Kids Manganese Deposit, Clark County, Nev.: Exploration, Mining, and Processing. BuMines RI 5209, 1956, 31 pp.

6. Kumke, C. A., C. K. Rose, F. D. Everett, and S. W. Hazen, Jr. Mining Investigations of Manganese Deposits in the Maggie Canyon Area, Artillery Mountains Region, Mohave County, Ariz. BuMines RI 5292, 1957, 87 pp.

7. Lasky, S. G., and B. N. Webber. Manganese Resources of the Artillery Mountains Region, Mohave County, Ariz. U.S. Geol. Survey Bull. 961, 1949, 86 pp.

8. McKelvey, V. E., J. H. Weise, and V. H. Johnson. Preliminary Report on the Bedded Manganese of the Lake Mead Region, Nevada and Arizona. U.S. Geol. Survey Bull. 948-D, 1949, pp. 83-101.

9. Miller, R. L. Manganese Deposits of Aroostook County, Maine. Maine Geol. Survey Bull. 4, 1947, 62 pp.

10. Pavlides, L. Geology and Manganese Deposits of the Maple and Hovey Mountains Area, Aroostook County, Maine. U.S. Geol. Survey Prof. Paper 362, 1962, 115 pp.

11. Prasky, C., R. L. Marovelli, and F. E. Joyce, Jr. Evaluating Cuyuna Manganese Resources by Sulfatizing. BuMines RI 5887, 1961, 27 pp.

12. Young, W. E. Manganese Occurences in the Eureka-Animas Forks Area of the San Juan Mountains, San Juan County, Colo. BuMines IC 8303, 1966, 52 pp.

APPENDIX A.—DESCRIPTION OF THE DEPOSITS

Manganese ore of the Hardshell Mine in Arizona occurs as replacements of fault gouge and silicified breccia and is believed to be hydrothermal in origin. The fault zone dips north at 35 to 40 degrees, and the lode is 3 to 18 meters thick. The average dimensions of the mineralization are 460 meters long, 275 meters wide, and 18 meters thick. The average depth to mineralization is 60 meters. The primary manganese minerals are pyrolusite, braunite, psilomelane, and wad. Silver halides are also present, as are other lead and zinc minerals.

The Maggie Mine, also located in Arizona, consists of alluvial-fan and playa deposits of early Pliocene age. The average depth to the mineralization is 177 meters, with average dimensions of the mineralization of 1,140 meters long, 720 meters wide, and 57 meters thick. The principal manganese minerals include psilomelane, wad, manganite, and pyrolusite.

The Sunnyside Mine in southwestern Colorado occurs in steeply dipping veins and breccia zones with mineralized widths up to 18 meters. The average dimensions of the deposit are 1,850 meters long, 610 meters wide, and 4.6 meters thick, with an average depth to mineralization of 50 meters. The primary manganese minerals are rhodonite and rhodochrosite.

The Maple Mountain-Hovey Mountain deposit in Aroostook County, Maine, occurs as a complex folded syncline with some faulting along the crests of Maple and Hovey Mountains. A mantle of glacial drift about 1 meter thick covers most of the deposit, but ore outcrops on the ends of the syncline near the crests of the mountains. The deposit is about 2,400 meters long and ranges in width from about 61 meters at the southwest end to 910 meters at the northeast end, and it is known to extend to 470 meters below the surface. The deposit occurs as a fine-textured manganiferous silicate sedimentary series of manganiferous hematitic slates enclosing a banded manganiferous hematite horizon. The primary manganese minerals are rhodochrosite, braunite, bementite, rhodonite, and spessartite.

The North Aroostook District in Maine contains 11 deposits. The Dudley and Gelot Hill deposits included in this study are sedimentary beds enclosed in shales and limestones, which have experienced low-grade metamorphism. Manganese-bearing strata may have dips greater than 60 degrees and extend to depths of more than 305 meters. The ore zones average 15 meters in thickness, and glacial drift about 1.8 meters thick covers most of the area. Dudley, the largest of the deposits in the district, measures about 1,830 meters long and 46 meters wide, and extends to depths greater than 366 meters. Braunite, bementite, and manganiferous carbonates are the most abundant manganese minerals.

The manganese deposits of the Cuyuna North Range in Minnesota consist of complexly folded and slightly metamorphosed sedimentary rocks with accompanying igneous flows. The deposits are steeply dipping and erratically oxidized in varying degrees to depths of 244 meters. Glacial drift averaging 20 to 45 meters in thickness covers most of the deposits, which range in thickness from 3 to 185 meters; and the majority of the resources occur within 60 meters of the surface. Manganiferous limonite, psilomelane, and manganite are the primary manganese minerals.

The Emma Mine deposit of the Butte District in Montana occurs as veins up to 30 meters wide in isolated blocks of old workings. The dimensions of the footwall vein are 4 to 6 meters wide, 1,200 meters long, and 600 meters deep. The dimensions of the hanging wall vein are 4 meters wide, 400 meters long, and 200 meters deep. Rhodochrosite and rhodonite are the principal manganese minerals and occur with silver, lead, and zinc minerals.

The Three Kids deposit in Nevada is in a graben on the northwest flank of the River Mountains in Clark County. Block faulting has broken the deposit into several ore bodies. The upthrown sides of the fault blocks were exposed to erosion that removed a large portion of the manganiferous material. The tabular manganiferous bed ranges from 30 to more than 1,100 meters in width. The manganiferous zone is up to 40 meters thick with an average overburden depth of 26 meters. The manganese within the tabular bodies occurs in lenses and pods, and as bedded nodules. Principal manganese minerals include wad, psilomelane, and pyrolusite. Minor amounts of copper, lead, zinc, and silver are associated with the manganese.

APPENDIX B.—PROPOSED MINING METHODS

The following proposed mining methods used to evaluate the domestic deposits are either a continuation of a prior mining operation or the mining method chosen by an evaluator to be the most feasible.

The Hardshell and the Maggie Mines would be mined by room-and-pillar methods. Twin boom jumbos, jackleg drills, and stopers would be used for development and production drilling. Ammonium nitrate-fuel oil (AN-FO) would be used for blasting. At the Hardshell Mine, LHD's would be used for loading, hauling, and dumping the ore. Broken ore would be dumped through grizzlies into the ore storage pocket, which would automatically load the skip at the skip loading station. Development would include sinking one shaft for production and service, and one shaft for ventilation. At the Maggie Mine, blasted ore would be transferred by LHD's from the rooms to the main haulageway where the ore would be crushed in a gyratory crusher. The crushed ore would then be transported by a conveyor out the main portal to a storage area. A front-end loader would load the stored ore into rear-end dump trucks to be hauled to the mill.

The Sunnyside Mine's current lead, zinc, and gold mining would be expanded to include manganese ore. Uncaved old openings would be mined by slabbing, and the manganese ore in the operating section of the mine would be selectively mined by overhand shrinkage stoping after the base metal ores are stoped. Ore would be blasted with AN-FO, drawn from the stope, and slushed down an ore chute into ore cars. It would be transported by locomotives (diesel and battery-operated) and dropped into ore cars on the American Tunnel level. Then ore would be transported out the American Tunnel and trucked from the mine portal to the mill.

The Maple Mountain-Hovey Mountain and Dudley and Gelot Hill deposits of Aroostook County, Maine, would be mined from an open pit, using shovels for excavation and trucks for hauling the waste and the ore to the mill. Drill rigs and AN-FO would be used to break up the ore. Development would include building access roads, removal of trees, clearing of stumps and vegetation and of overburden including stockpiling topsoil.

The deposits in the Cuyuna North Range would be mined from an open pit, using electric shovels for excavation and rear-end dump trucks for hauling the ore and waste. Overburden, waste, and ore would be drilled and blasted. Ore from some open pits would be hauled by truck to the mill, while ore from other pits would be loaded onto trains from trucks for transport to the mill. Development would include pumping out water from the old open pits, removal of trees, clearing of stumps and vegetation, and removal of overburden.

The Emma Mine of the Butte District would be mined from old workings using cut-and-fill stoping by proceeding up the dip from the haulage level. Ore would be removed from the full length of the block by backstoping. Broken ore would be slushed down chutes into ore cars on the haulage level. Battery-powered trains would transport the ore to an ore pocket at the shaft. From there the ore would be hoisted from the ore pocket to the surface and hauled by truck to the mill. Waste rock would be removed and transported in the same manner as the ore, except waste rock would be hauled to the Berkeley pit waste disposal area. After each slice of ore is taken from a stope, sandfill for ground support would be pumped into the excavation. Development would include pumping out water from the flooded old workings, sinking a concrete-lined circular shaft and driving drifts and raises.

The Three Kids Mine would be mined by extending old open pits northward from existing high walls. Overburden would be removed by electric shovels and hauled by truck to stacking areas for future backfill in the pits. All overburden except alluvial gravel would be drilled and blasted. Ore would be loaded with front-end loaders and hauled by truck to the mill.

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