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World resources of manganese appear ample for the foreseeable future; however, political and economic events in the last two decades have caused concern over the availability and reliability of an uninterrupted supply. Because of this concern, the U.S. Congress requested that the U.S. Bureau of Mines (USBM) initiate a study of the flow of tier-one strategic and critical materials in the economy that would delineate and quantify the production areas where metal values are lost. As a result, USBM has developed for strategic and critical materials a generic computerized commodity flow model that it is readily amenable to updating. The original model developed for cobalt, with slight modifications, was used to track the flow of manganese. This report follows the flow of manganese through its metallurgical and chemical applications and highlights areas where significant losses occur owing to downgrading, export, or disposal. The study indicates that materials containing 695,000 st of manganese were consumed in domestically 1990. Scrap recovery specifically for manganese recycling was insignificant. However, considerable manganese was recycled through processing operations as a minor component of ferrous and nonferrous scrap and steel slag. The major loss category is manganese lost in steel processing, 323,156 st or 46 percent of the 1990 apparent consumption. Most of this loss reports to steelmaking slags. While recovery from slags is technically feasible, it is not economically feasible.

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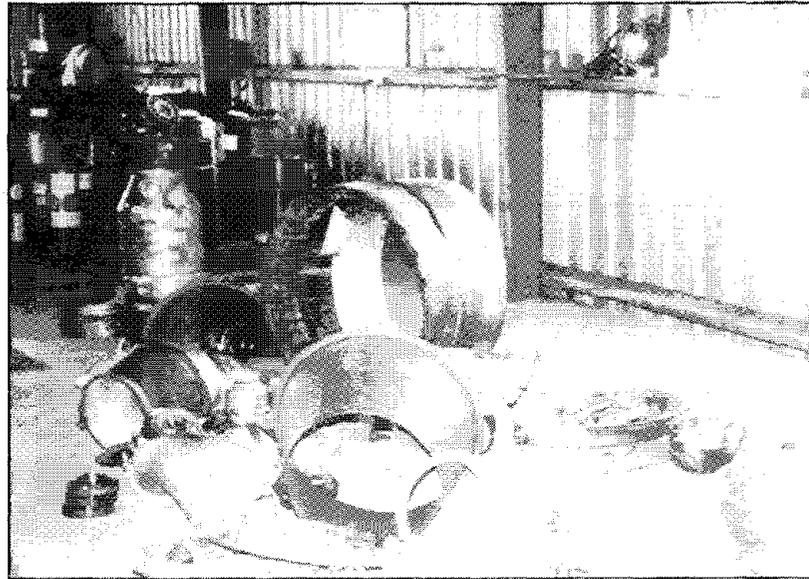
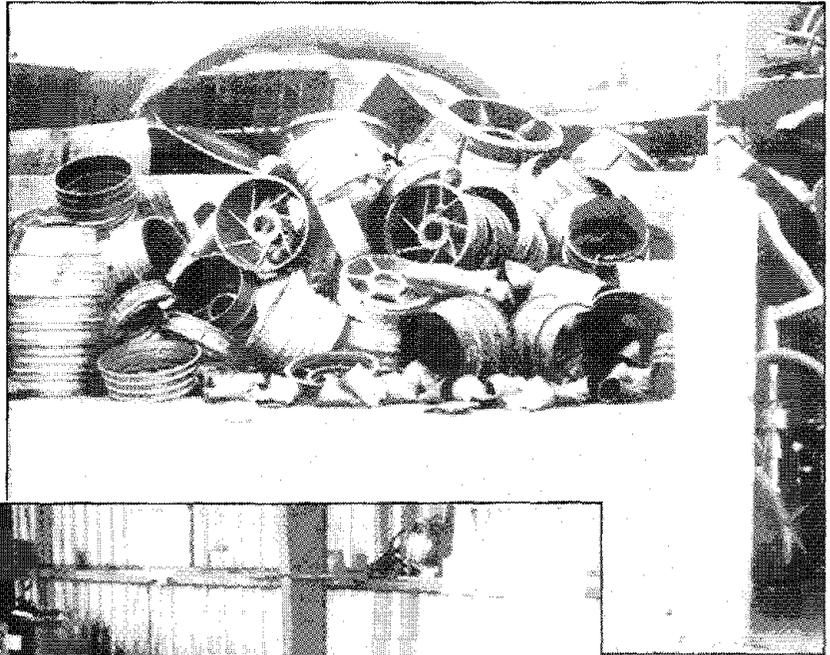
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A Manganese Consumption and Recycling Flow Model

By Robert C. Gabler, Jr.



UNITED STATES DEPARTMENT OF THE INTERIOR



BUREAU OF MINES

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Information Circular 9421

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By Robert C. Gabler, Jr.

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Bruce Babbitt, Secretary**

**BUREAU OF MINES
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

kg	kilogram	ppm	part per million
kg/t	kilogram per metric ton	t	metric ton
pct	percent		

U.S. Customary Units

lb	pound	st	short ton
lb/st	pound per short ton		

Note: The flow model for manganese uses short tons. To convert to metric tons, multiply by 0.907185.

A MANGANESE CONSUMPTION AND RECYCLING FLOW MODEL

By Robert C. Gabler, Jr.¹

ABSTRACT

Because of concern over the availability and reliability of an uninterrupted supply of manganese and other materials, the U.S. Congress requested that the U.S. Bureau of Mines (USBM) study the flow of strategic and critical materials in the economy to delineate and quantify the production areas where metal values are lost. As a result, the USBM developed a generic computerized commodity flow model that is readily amenable to updating. The original model developed for cobalt, with slight modifications, was used to track the flow of manganese.

This report follows the flow of manganese through its metallurgical and chemical applications and highlights areas where significant losses occur owing to downgrading, export, or disposal. The study indicates that materials containing 695,000 short tons (st) of manganese were consumed domestically in 1990. Scrap recovery specifically for manganese recycling was insignificant. However, considerable manganese was recycled through processing operations as a minor component of ferrous and nonferrous scrap and steel slag. The major loss category is manganese lost in steel processing, 323,156 st or 46 pct of the 1990 apparent consumption. Most of this loss reports to steelmaking slags. Recovery from slags is technically feasible, but is not economically feasible.

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INTRODUCTION

Manganese is essential to iron and steel production in the United States. Demand in metallurgical applications accounts for most of the manganese consumed in the United States, with ironmaking and steelmaking alone consuming 82 pct (1).² The importance of manganese is related to the functions it performs. Manganese controls oxygen and sulfur impurities in steel, increases the strength, toughness, hardness, and hardenability of steel, and inhibits formation of embrittling grain boundary carbides (2). Normally, manganese metal is a brittle and unworkable substance; however, when alloyed in steels and other metals, it acts to produce tougher, harder, and stronger alloys (2). No economic substitute for manganese in iron and steel has been found. Thus, a continued secure supply of manganese is vital to any defense effort as well as to maintenance and growth of the U.S. economy (2).

The United States currently is dependent on foreign supplies of manganese, imported as ore, ferroalloy, or metal. The largest supplier of U.S. demand is the Republic of South Africa, followed by France, Australia, Gabon, Mexico, and Brazil (1) (table 1). Most production of manganese is expected to continue to come from the Republic of South Africa, where the largest reserves by far are located (2).

Table 1.—U.S. major import sources for manganese in 1990

Country	Mn content, st	Pct of total
South Africa, Republic of . . .	175,990	26.1
France	96,282	14.3
Australia	77,780	11.5
Gabon ¹	74,766	11.1
Mexico	70,534	10.4
Brazil	60,081	8.9
All others	119,581	17.7
Total	675,014	100.0

¹Jones (1) stated that data for Gabon may be lower than reported here.

World resources of manganese are ample for the foreseeable future (3), as are the resources of chromium, cobalt, and the platinum-group metals (PGM). However, past political and economic events have raised concern about the uninterrupted availability and reliability of supplies of these commodities. For this reason, these metals are considered strategic and critical materials. The risks of future disruptions of supply were considered high around the time of the 1978 Katangese rebellion in Zaire (4-5). The price of cobalt rose from \$11/kg (\$5/lb) in

²Italic numbers in parentheses refer to items in the list of references preceding the appendix.

1977 to \$51/kg (\$23/lb) in 1979. Even though some of this price increase was due to sharply increased demand, the rapid changes in the cobalt market generated significant concern about future disruptions to the supply of cobalt, and also chromium, manganese, and PGM. This concern led to studies on the strategic importance, availability, and supply vulnerability of a number of commodities, including manganese (5-13). Most of these studies either are now out of date or do not supply information on losses of the strategic and critical commodities due to waste disposal, downgrading, and/or export. The lack of knowledge on these unknown losses makes conservation efforts difficult.

Industry officials in the production, manufacturing, and recycling of strategic and critical commodities are reluctant to discuss the quantities of materials that go to disposal, downgrading, and export. This information is often considered to be proprietary in nature. Even when data are available, there is confusion between disposition of materials and recycling. For example, in a survey of seven scrap recyclers in 1987 (14), the following estimates were obtained for disposition of scrap from the superalloy industry:

	Range, pct
Domestic recycling	60-100
Exports	0- 40
Recycled scrap:	
Domestic remelting	75-100
Recycling to same superalloy	38- 90
Recycling to other high-value superalloy	5- 38
Downgrading	10- 25
Discarding	3- 5

These estimates are typical of the data on processing, manufacturing, disposal, downgrading, and recycling of strategic and critical materials. Therein lies the difficulty in determining the amounts of critical and strategic commodities that are discarded, downgraded, or exported. This study was conducted to ascertain how the United States is using and losing its strategic and critical materials.

In 1980, the USBM reported the results of contract studies by Inco Research and Development Center, Suffern, NY, and Arthur D. Little, Inc., Cambridge, MA, to assess the domestic availability of chromium in scrap metal and the amount of scrap being recycled (15-16). These reports contain data up to 1976 and 1978, respectively; no updates of these studies were conducted following their publication. In 1976 and 1981, the National Materials Advisory Board (NMAB) conducted studies on the consumption of manganese, its strategic importance, and reserves and resources of the world (17).

In May 1985, the U.S. Congress, Office of Technology Assessment (OTA), produced a study entitled "Strategic Materials: Technologies To Reduce U.S. Import Vulnerability" (18). Included in the study was a set of recommendations to the USBM to conduct a survey of recycling-related activities. OTA recommended a scrap recycling study to update the chromium scrap metal information contained in two USBM publications (15-16), as well as to expand the scope of the previous studies to include information on scrap generated by the cobalt, manganese, and PGM industries, and to include the wastes generated by all the various industrial and Department of Defense (DOD) users of these four commodities.

Acting on this recommendation, in 1987 the USBM initiated a study of the four commodities. The main objective of this study was to produce a commodity-oriented structural model that would trace flow, recycling, and

final disposition of the four identified commodities. The model then could be updated in subsequent years. A second objective of the study was to provide, in an understandable manner, an overview of the commodity flow. This overview would serve as a tool for the Congress and for industry associations to help in the study of that commodity's vulnerability to political and availability factors outside the control of the United States. Another objective of the study was to highlight significant commodity loss areas where further research was required.

A hierarchical model was developed for the commodity cobalt (19-20). The model is generic and can be applied to other strategic and critical commodities. The model was applied to cobalt, chromium, and PGM. To meet the stated objectives of this study, the model also was applied to manganese, with slight modification.

DESCRIPTION OF FLOW MODEL

As stated in the introduction, the manganese flow model is based on the generic flow model developed for the commodities cobalt, chromium, and PGM, with some minor modifications. Development of the model was an iterative process; thus, the manganese model is the most comprehensive version of the commodity flow model.

The flow model shown here is a "snapshot" of a dynamically changing industry. This particular snapshot was taken in late 1992 using the data available at that time. Subsequent new information could, and in a few instances, does change the data displayed. However, only the data available at the time of the original writing are shown. Others could and should use the newest available data when updating this flow model.

DEFINITIONS

Apparent consumption.—Production plus net trade plus stock changes. (Note that neither reported nor apparent consumption is actual consumption. However, apparent consumption is very close to actual consumption.) A more detailed definition and calculation of apparent consumption is in the appendix.

Production.—Domestic mine production plus recycle.

Net trade.—Imports minus exports.

Stock change.—Beginning minus ending stocks (21).

Consumption.—Apparent consumption, except where it is listed as reported consumption.

Reported consumption.—Those data reported to the USBM in response to the Bureau's industry consumption survey questionnaires. In addition, estimated data from

nonrespondents is often included in USBM reported consumption tables.

Home scrap.—Scrap generated during processing that is internally recycled within the generating company and that can be considered as being endlessly recirculated. It is some times referred to as "run-around scrap." It is not counted as part of consumption.

Obsolete scrap.—Scrap generated by users and recyclers when used products are overhauled or when the product has reached the end of its productive life cycle (16).

Prompt scrap.—Also called prompt industrial scrap or new scrap; consists of solids, turnings, grindings, sludges, and liquors generated during the manufacturing process when the primary product is fabricated into a finished product (16).

Run-around scrap.—Home scrap.

Losses.—Materials such as fume, spilled contaminated metal, scale, metal trapped in slag, material removed in pickling, plating wastes, grinding, etc.

Downgraded scrap.—Scrap that is used for lower grade alloy, such as superalloy scrap used for stainless steel or alloy steel scrap used for cast iron.

Recovery.—The practice of acquiring metals from obsolete material for recycle into new products.

Recovery loss.—Those obsolete materials that are never collected for recycling. An example is obsolete material used as landfill.

Recycle.—The process of collecting, cleaning, assaying, and sorting materials for reuse in industry.

Recycling loss.—Those losses that occur in the recycling process. For example: A major loss area is downgraded

scrap material that gets recycled to lower quality metals, particularly where the metal in question is not required for the new alloy but is acceptable in the new alloy products.

Manganese ferroalloy and metal.—Ferromanganese plus silicomanganese plus manganese metal.

Manganese ferroalloy.—Ferromanganese plus silicomanganese.

Ferromanganese.—High-, medium-, plus low-carbon ferromanganese.

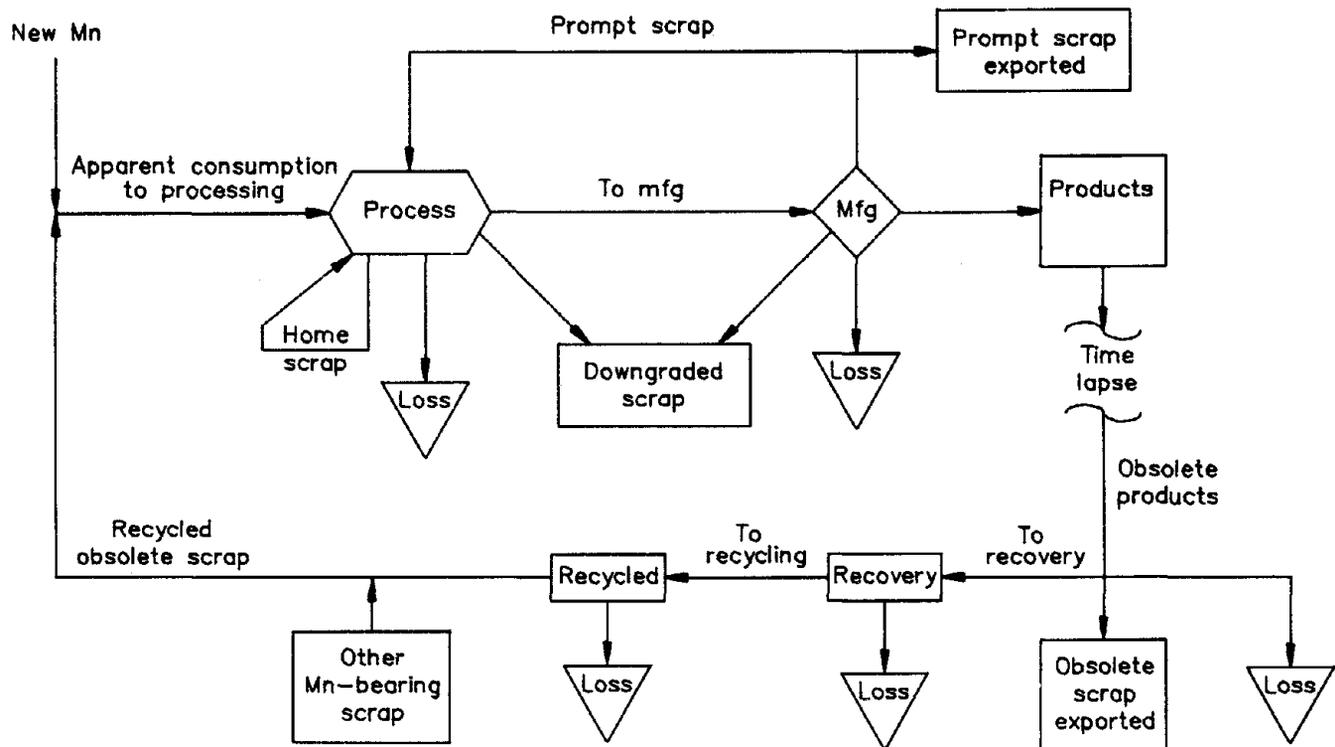
Ferrous alloys.—All ferroalloys including ferrochromium, ferrochromium-silicon, ferromanganese, ferrosilicon, ferromanganese, ferroboron, ferrovandium, ferrotitanium, ferrotungsten, etc.

GENERAL CONFIGURATION

A typical manganese flow model is shown in figure 1. The appendix discusses the mathematical relationships in the model and gives the details of its application to the data for 1990. The percentage data come from calculated and estimated values shown in the appendix in table A-35. The supplies of new manganese come from imports of manganese ore, manganese ferroalloys, manganese

chemicals, and metal, which are augmented by secondary production (scrap). In any given year, fractions of these materials go to exports, stocks, domestic processing, and manufacturing. Prompt scrap also augments the input of new manganese and scrap. During processing, about 14 pct of input reports as home scrap and is internally recycled. About 50 pct of input reports to processing losses, about 4 pct reports to downgraded material, and about 51 pct reports to manufacturing. Note that home scrap is not counted, as it is endlessly recycled, and counting it would be double counting. However, it is part of the recycling of the commodity. The processed material then goes to product manufacturing. During manufacturing, a small amount of manganese (about 5.5 pct) reports as losses and some reports as downgraded material (about 5 pct). The remainder goes to final products. Prompt scrap amounts to about 5.5 pct, of which 0.4 pct goes to export and the remainder to processing. After a normal use life, each product that is not in a dissipative end use becomes obsolete scrap and waste. The estimated amount recycled, based on literature data, was about 11.9 pct (81,800 st). Most of this recycled material is recycled for its iron content, but not for its manganese content.

Figure 1



Typical flow model for manganese industry.

PROPERTIES OF FLOW MODEL

The flow model described in IC 9252 (19) and IC 9303 (22) is generic in nature and, thus, can be used for a wide variety of commodities with only minor modifications. The model is easily updated and generally understood by the public, and it highlights areas where recycling research is needed. The model is hierarchical, with three levels: the entire manganese industry, the individual industry level, and the individual plant level. The data in this report cover the entire manganese industry and the individual industry level.

ASSUMPTIONS IN MODEL

In the development of the model, a number of assumptions had to be made. These are as follows:

1. Where data were found, the percentages reporting in each category were used. Where no current data were available, data from NMAB 406 were used and assumed to be still applicable (5).

2. The use lives of various products vary over a wide range. NMAB estimated the life spans of a number of products (5). Its estimation for the life spans of

superalloys, stainless and heat-resistant (SHR) steels, full alloy steels, high-strength low-alloy (HSLA) steels, tool steels, and unspecified steels was 5 years. For other alloys (based on aluminum food-handling products and manganese bronze ship parts), life span was estimated to be 10 years. The life spans of carbon steels and cast irons are based on the current life cycles of automobiles and light trucks because of those industries' high consumption of these materials. Currently, the life cycle of a motor vehicle is estimated to be about 10 years (18). The life span of miscellaneous and unspecified materials is assumed to be 5 years, based on the most frequent life spans of metal products. Chemical and battery products are nearly all used in dissipative end uses and are not recycled.

3. Thus, it is assumed that obsolete scrap available for recycle in 1990 would come from 1980 consumption of carbon steels, cast irons, and other alloys, and from 1985 consumption of superalloys, SHR steels, full alloy steels, HSLA steels, tool steels, unspecified steels, and miscellaneous and unspecified metal products.

4. Unless otherwise stated, all manganese quantities are short tons of contained manganese. All values reported are the best estimates possible with currently available data.

MANGANESE INDUSTRY

Most manganese is consumed by the iron and steel industries in the United States. The metallurgical industry consumes about 88 pct; the chemical and battery industries, about 12 pct. The major overall end use is for carbon steels, which account for about 70 pct of metallurgical consumption or about 61 pct of total apparent consumption of manganese.

In 1990, the United States imported 100 pct of any new manganese consumed. There has been a trend in manganese-producing countries to vertically integrate their manganese industry by developing their own manganese ferroalloy production facilities. This has led to a significant change in the percentages of manganese imported as manganese ore versus manganese imported as ferroalloys. Ore imports have fallen from 79 pct of imports in 1969 to 25 pct in 1990, whereas manganese ferroalloy imports have risen from 21 pct in 1969 to 75 pct in 1990 (1-2, 23). This trend of producer nations toward their own production of manganese ferroalloys and metal has contributed to a decline in U.S. ferroalloy production.

The breakdown of manganese consumption in U.S. industries in 1990 is shown in tables 2 and 3, and an overview of the U.S. manganese industry is shown in figure 2.

In 1990, the input to manganese-consuming industries included domestic production of 1,000 st of contained manganese, manganese ore containing 169,000 st of manganese, ferroalloys and metal containing 505,000 st of manganese, shipment of stockpile excesses of 22,000 st of manganese, and industry stocks containing 324,000 st of manganese. Total input equals 1,021,000 st of contained manganese. Of this amount, 60,000 st was exported as ore, manganese ferroalloys, and metal. Another 266,000 st of contained manganese reported back to industry stocks, leaving 58,000 st for consumption from industry stocks. Materials containing 634,214 st of manganese went directly to the manganese-consuming industries, and ore containing 60,786 st of manganese was sent to U.S. ferroalloy producers. During manganese ferroalloy processing, 6,786 st of manganese contained in slag and particulates reported as losses, while 54,000 st of manganese reported to manganese-consuming industries as ferroalloy.

The metallurgical industries consumed materials containing 602,212 st of manganese. The manganese chemical industries consumed material (mostly ore) containing 40,000 st of manganese, and the battery industry consumed ore containing 46,000 st of manganese.

Table 2.—Apparent consumption of manganese by various industries in 1990

<i>Industry</i>	<i>Apparent consumption, st of contained Mn</i>
Metallurgical industry:	
Steels:	
Carbon	422,085
SHR	23,059
Full alloy	61,988
HSLA	39,124
Tool	334
Unspecified	3,417
Cast irons	16,026
Superalloys	239
Other alloys ¹	26,286
Miscellaneous and unspecified materials	9,654
Ferroalloy production losses	6,786
Chemical industry	40,000
Battery industry	46,000
Total	694,998

¹Except steel alloys and superalloys.

Table 3.—Manganese supply-demand relationships¹ for 1990

	<i>Contained Mn, 10³ st</i>
Components of U.S. supply:	
Domestic mines ²	1
Shipment of Government stockpile excesses	22
Imports, ore and dioxide ¹	169
Imports, ferroalloy and metal	505
Industry stocks, 1/1/90	324
Total U.S. supply	1,021
Distribution of U.S. supply:	
Industry stocks, 12/31/90	266
Exports, ore	46
Exports, ferroalloy and metal	14
Industrial demand	695
U.S. demand pattern: ³	
Appliances and equipment	10
Batteries	46
Cans and containers	24
Chemicals ⁴	40
Construction	152
Machinery	82
Oil and gas industries	15
Transportation	50
Other ⁵	276
Total U.S. primary demand	695

¹Where available, data for MnO² are included.

²Including manganiferous ore.

³New series for steel-related end uses beginning in 1989.

⁴Includes miscellaneous nonmetallurgical uses of ore.

⁵Not based specifically on reported data; includes processing losses. Includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

The only significant current domestic supply of manganese is recycled scrap. However, processing iron and steel scrap for recovery of manganese is insignificant (2). Steels are recycled primarily for their iron content. A furnace charge for steels may consist of as much as 53 pct prompt and purchased steel scrap (18), while cast iron furnace charges may contain 94 pct scrap (24). Other alloys containing manganese may be recycled, but not specifically for their manganese content. (An example is aluminum beverage cans, which are recycled for their aluminum content.) Manganese chemicals and batteries generally are consumed in dissipative end uses and, thus, are not recycled.

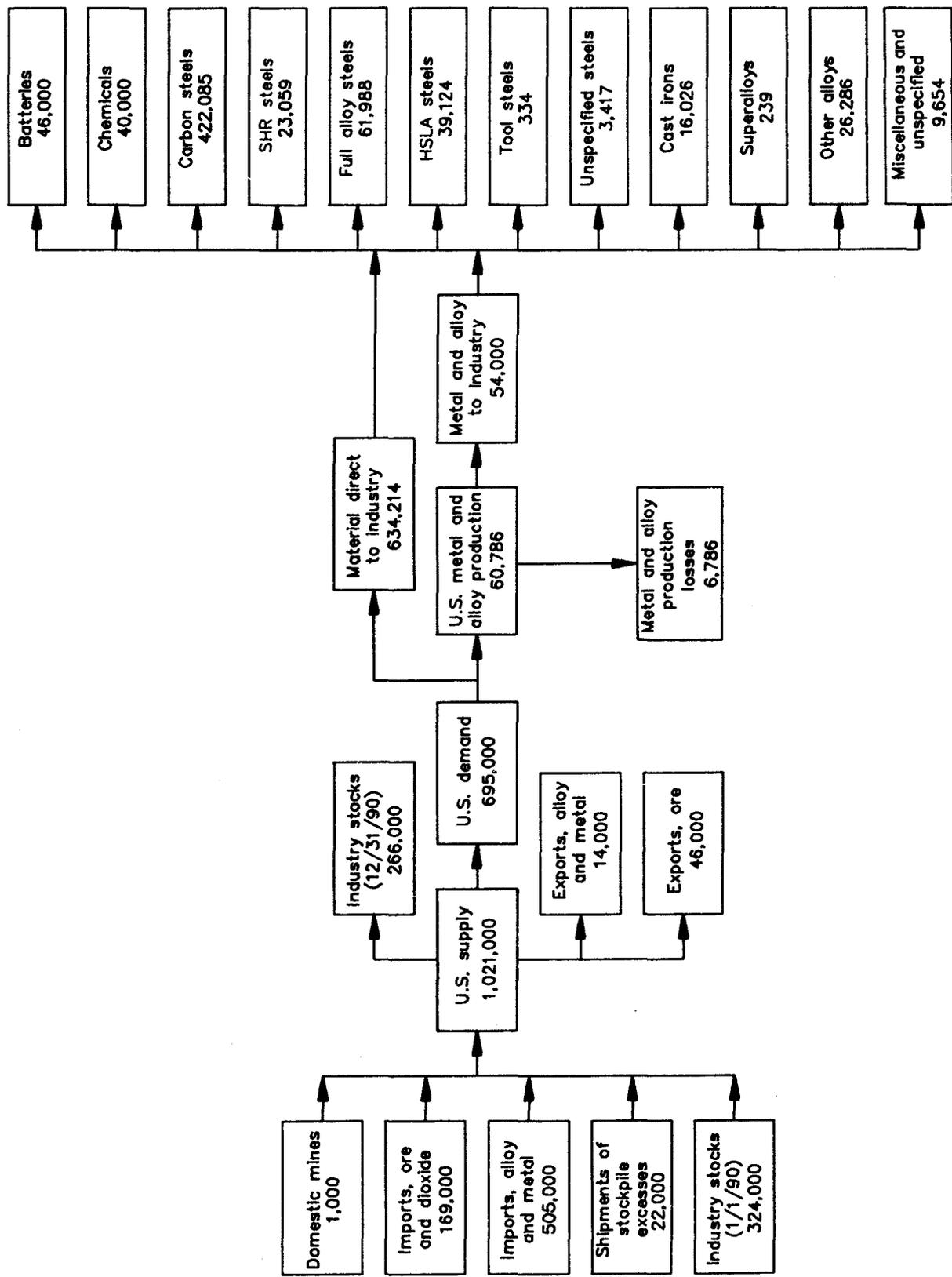
CARBON STEELS

Carbon steels are consumed in the manufacture of automobiles, appliances, structural steels, and a wide variety of other products. During 1990, the carbon steel industry consumed 422,085 st of manganese, mostly in the form of manganese ferroalloys. The flow model for manganese in carbon steels is shown in figure 3. An additional 17,398 st of manganese in prompt scrap and 56,880 st of manganese in home scrap also were consumed during processing. Material containing 247,996 st of manganese reported to processing losses (slags, dusts, etc.). Other materials containing 21,222 st of manganese were downgraded to lesser materials. The remaining material, containing 170,265 st of manganese, reported to product manufacturing.

During manufacturing, material containing 17,398 st of manganese was recycled to processing as prompt scrap, material containing 26,617 st of manganese was downgraded to lesser metals, and material containing 26,617 st of manganese reported to manufacturing losses (dusts, contaminated metal, grindings, etc.). Carbon steel final products contained 99,633 st of manganese.

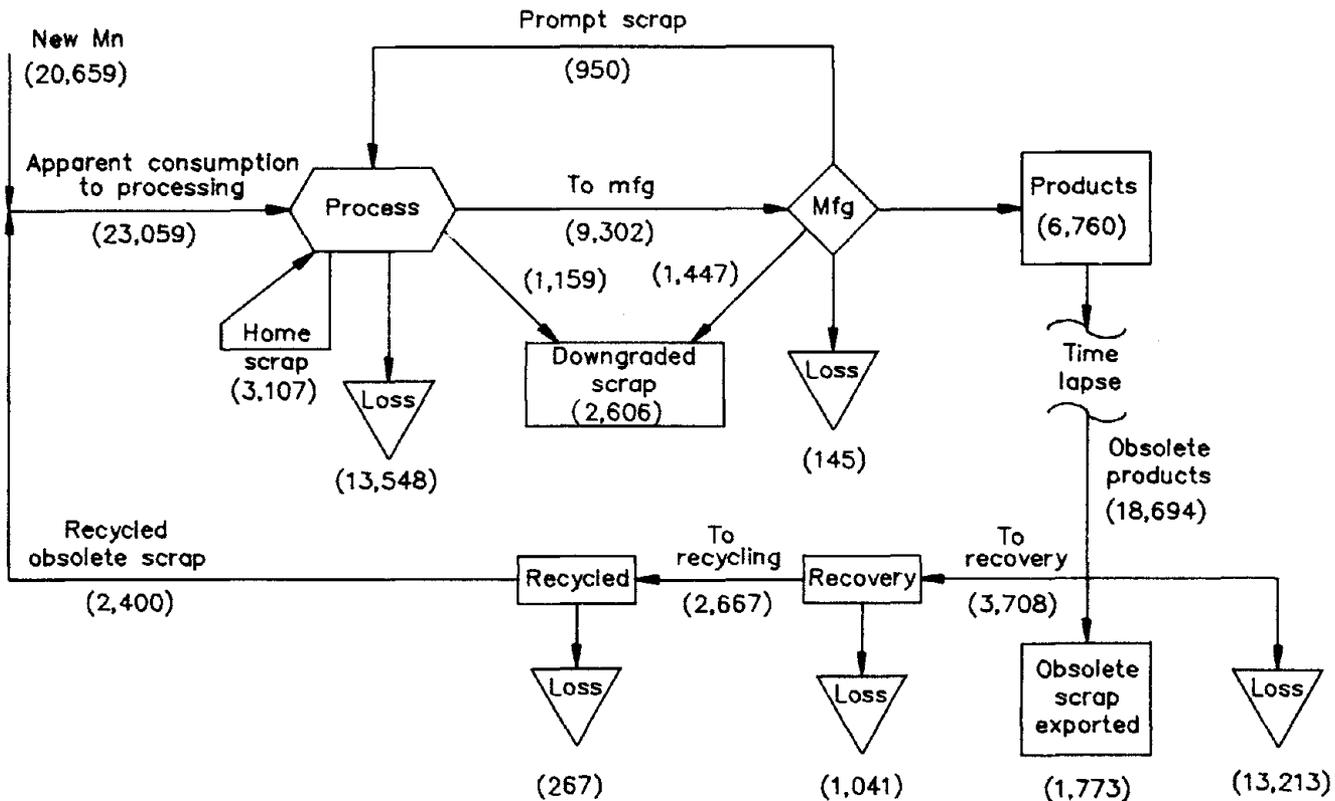
Because carbon steel products are heavily used in automobiles and appliances and these products are estimated to have a 10-year life cycle, it is assumed that carbon steels have a 10-year life cycle (18). Material containing 687,434 st of manganese from 1980 carbon steel industry consumption was potentially available for recycling. While considerable amounts of this material were recycled to various steel melts as part of the scrap charges to the furnaces, essentially none was recycled specifically for its manganese content. During 1980 production, 525,124 st of manganese reported to losses and downgraded material. Material containing 162,310 st of manganese was available for recovery. Unknown and unrecovered losses amounted to 113,508 st of contained manganese. Feed to recycling contained 48,802 st of manganese. During recycling, material containing 4,880 st of manganese was lost. Scrap containing 43,922 st of manganese was recycled in 1990.

Figure 2



Overview of manganese industry in United States, 1990; amounts are in short tons.

Figure 4



Stainless and heat-resistant steels flow model, 1990; amounts are in short tons.

alloy steels is shown in figure 5. New manganese material feed to processing contained 55,538 st of manganese. Obsolete scrap containing 6,450 st of manganese was also consumed. Additional feed to processing was home scrap containing 8,354 st of manganese and prompt scrap containing 2,555 st of manganese. During processing, loss material containing 36,421 st of manganese and downgraded material containing 3,117 st of manganese were generated. Processing material feed to manufacturing contained 25,005 st of manganese.

During manufacturing, in addition to prompt scrap, loss materials containing 3,907 st of manganese and downgraded material containing 3,907 st of manganese were produced. Final products contained 14,635 st of manganese.

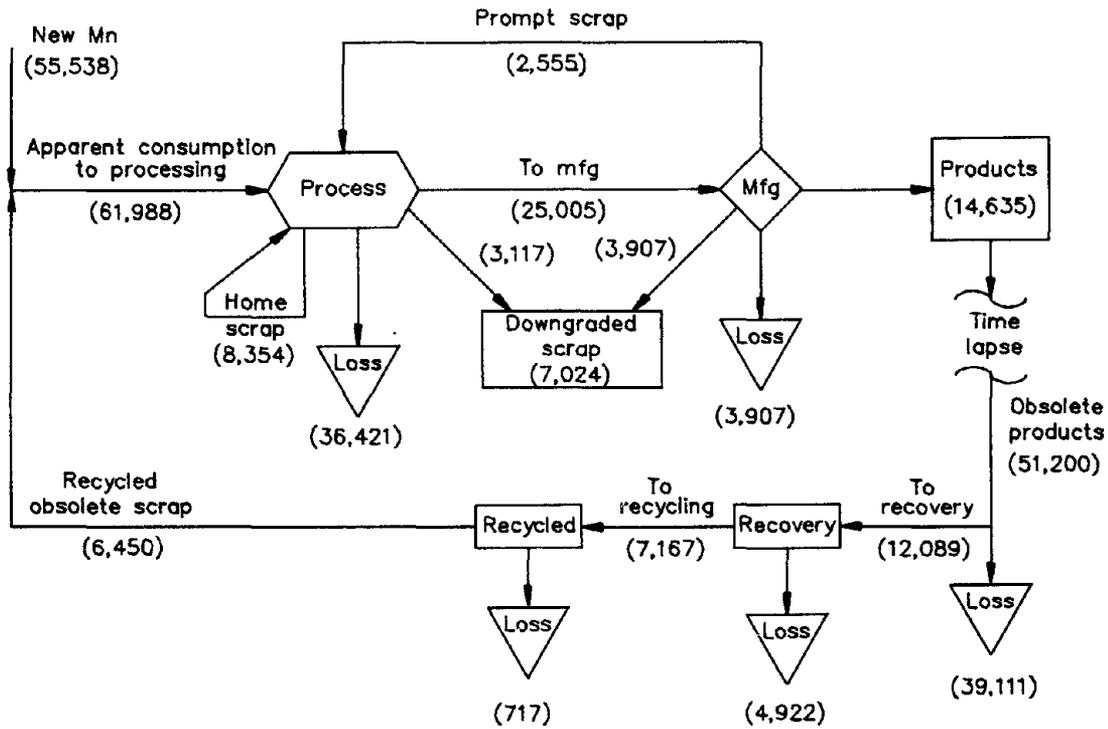
Potentially available material for recycling was provided by 1985 apparent consumption of manganese for full alloy steels. This material contained 51,200 st of manganese. Production losses contained 39,111 st of manganese, leaving material containing 12,089 st of manganese for recovery. Unknown and unrecovered material containing 4,922 st of manganese was lost. Recovered material containing 7,167 st of manganese reported to recycling. Recycling loss material contained 717 st of manganese, while scrap containing 6,450 st of manganese was recycled.

HIGH-STRENGTH LOW-ALLOY STEELS

These alloys originally were developed for the Alaska Pipeline, where environmental conditions required unusually high strength materials (26). These steels are now used extensively as structural steels in automobiles, buildings, and bridges, as well as having some uses where the properties of these steels protect against atmospheric corrosion. The flow model for HSLA steels is shown in figure 6. Feed to processing included new material containing 35,053 st of manganese, obsolete scrap containing 4,071 st of manganese, prompt scrap containing 1,613 st of manganese, and home scrap containing 5,272 st of manganese. During processing, loss material containing 22,987 st of manganese and downgraded material containing 1,967 st of manganese were generated. The remaining material, containing 15,782 st of manganese, went as feed to manufacturing.

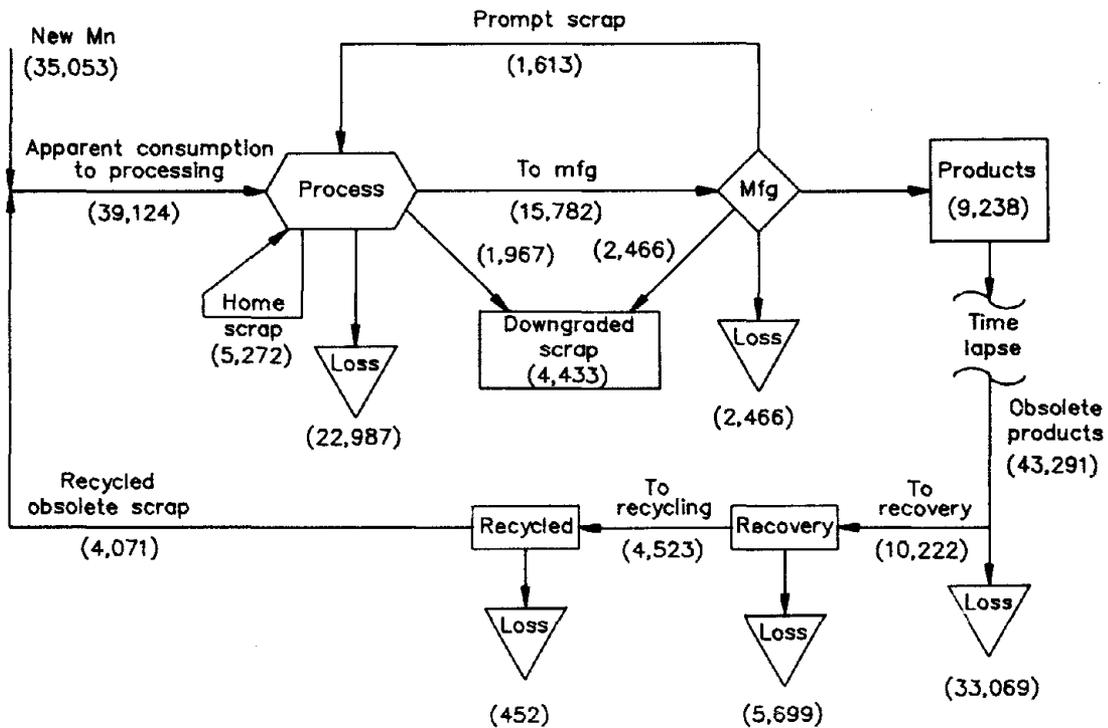
During manufacturing, prompt scrap containing 1,613 st of manganese, loss material containing 2,466 st of manganese, and downgraded material containing 2,466 st of manganese were produced. Final products contained 9,238 st of manganese.

Figure 5



Full alloy steels flow model, 1990; amounts are in short tons.

Figure 6



High-strength low-alloy steels flow model, 1990; amounts are in short tons.

From 1985 apparent consumption of manganese in HSLA steels, material containing 43,291 st of manganese was potentially available for recycling. Production losses contained 33,069 st of manganese. Unknown and unrecovered loss material contained 5,699 st of manganese. During recycling, material containing 452 st of manganese was lost. The remaining material was recycled obsolete scrap that contained 4,071 st of manganese. Total losses in HSLA steels in 1990 were estimated to contain 36,037 st of manganese.

TOOL STEELS

Tool steels are designed for cutting, forming, or otherwise shaping a material. The flow model for tool steels is shown in figure 7. New material containing 299 st of manganese, obsolete scrap containing 35 st of manganese, prompt scrap containing 14 st of manganese, and home scrap containing 45 st of manganese were the feed to processing. Loss material containing 196 st of manganese and downgraded scrap containing 17 st of manganese were produced during processing. Processed material containing 135 st of manganese was sent as feed to manufacturing. Manufacturing losses contained 21 st of manganese. Final products contained 79 st of manganese. Obsolete products containing 440 st of manganese were produced. During manufacturing, prompt scrap containing 14 st of manganese, downgraded scrap containing 21 st of manganese, and loss material containing 21 st of manganese were produced. The final products contained 79 st of manganese.

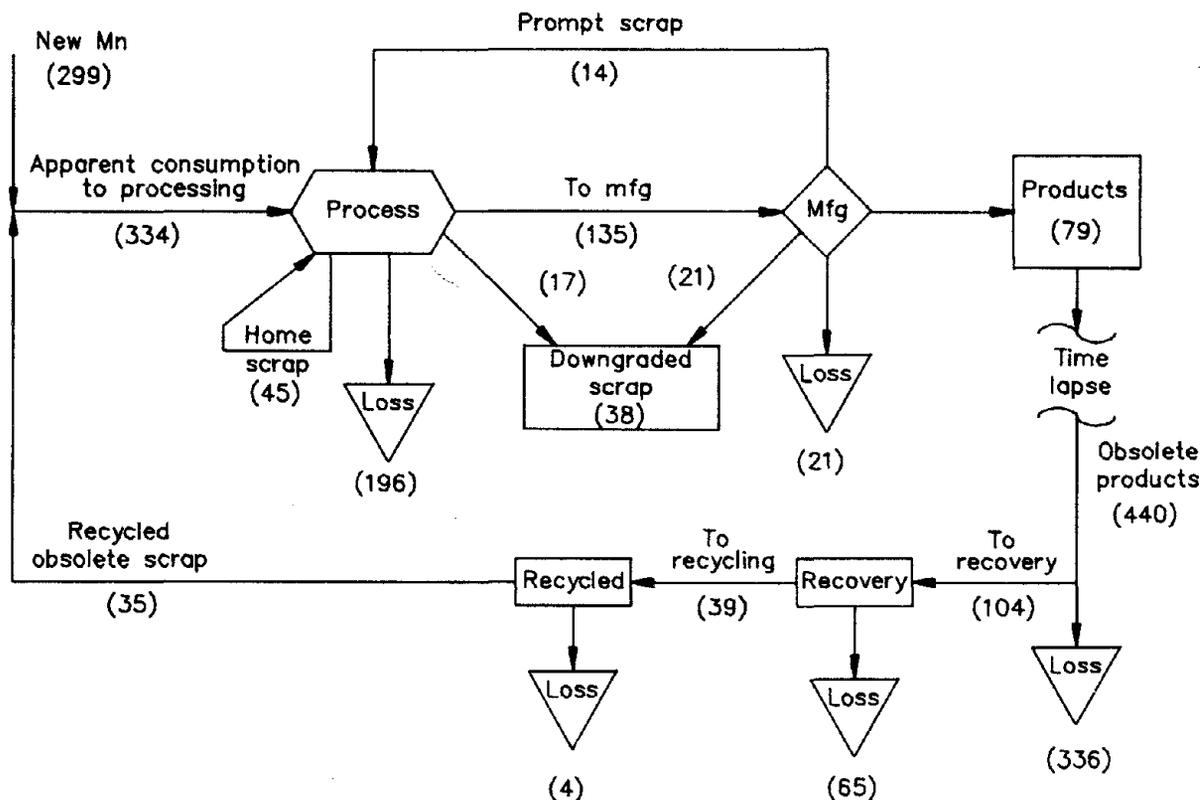
Material containing 440 st of manganese from 1985 apparent consumption of manganese in tool steels was potentially available for recovery and recycling. Production losses in 1985 contained 336 st of manganese. Unknown and unrecovered loss material contained 65 st of manganese. Of the material sent to recycling (39 st of contained manganese), recycling losses contained 4 st of manganese. Obsolete scrap recycled in 1990 for tool steels contained 35 st of manganese.

During manufacturing, prompt scrap containing 14 st of manganese, downgraded scrap containing 21 st of manganese, and loss material containing 21 st of manganese were produced. The final products contained 79 st of manganese.

UNSPECIFIED STEELS

This category includes, as a minor component, steels for which the surveyed companies did not specify the type(s) of steel, and steel categories for which the data had to be combined to avoid revealing company proprietary data, including high-, medium-, and low-carbon ferromanganese in electric steels; medium- and low-carbon ferromanganese in SHR steels; silicomanganese in electric and tool steels;

Figure 7



Tool steels flow model, 1990; amounts are in short tons.

and manganese metal in carbon steels, HSLA steels, and electric steels (I). For these steels, the "all steels" flow model shown in figure 8 was used.

Material feed to processing included 3,061 st of contained manganese in new manganese, 356 st of manganese in obsolete steel scrap, 141 st of manganese in prompt scrap, and 460 st of manganese in home scrap. During processing, loss material containing 2,008 st of manganese and downgraded scrap containing 172 st of manganese were generated. Processed steel containing 1,378 st of manganese was sent to manufacturing.

During manufacturing, downgraded scrap containing 215 st of manganese and loss material containing 215 st of manganese were generated. The final products contained 807 st of manganese.

Material consumed in 1985 was potentially available for recycling and contained 1,442 st of manganese. During production in 1985, losses amounted to 1,102 st of contained manganese. Unknown and unrecovered losses were small and were added to recycling losses. Recycling loss material contained 34 st of manganese. Obsolete scrap containing 306 st of manganese was recycled. The amount of recycled obsolete scrap from 1985 production of unspecified steels was less than the amount of material

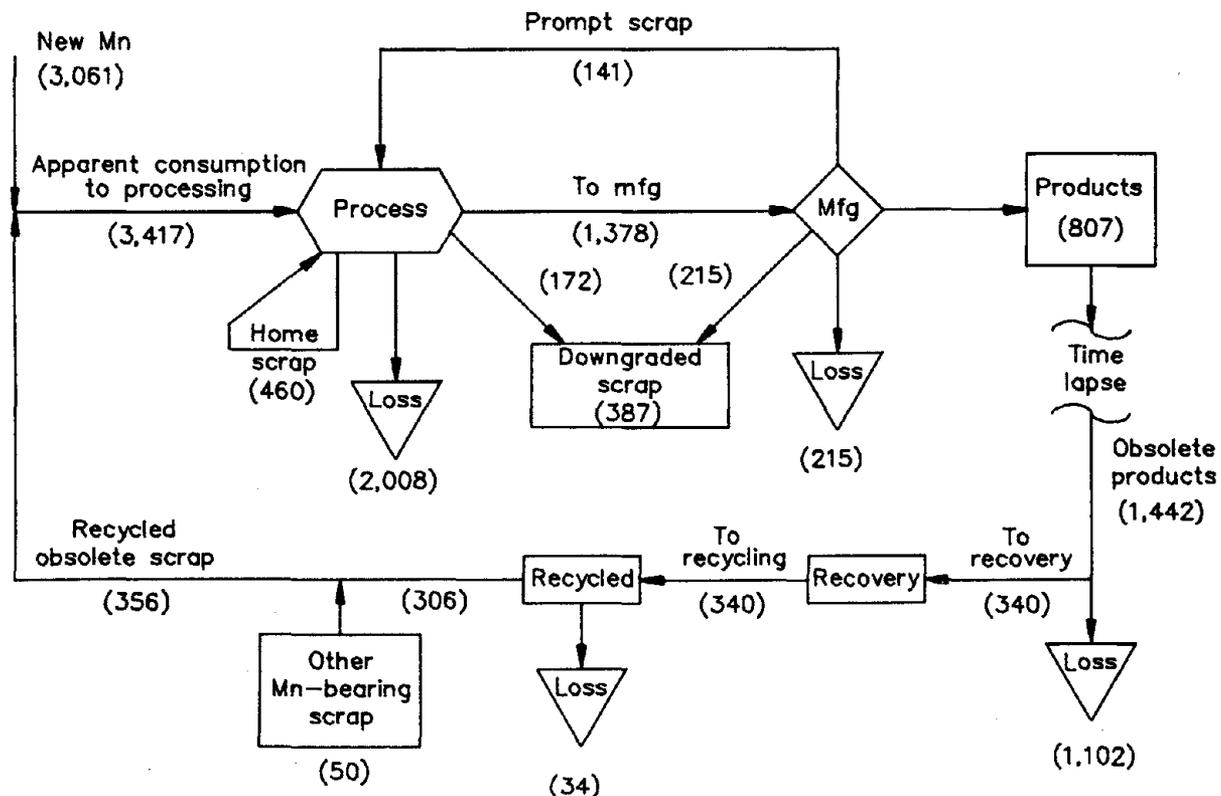
estimated to be recycled in this end use. Thus, obsolete scrap from other end uses (possibly downgraded scrap) containing 50 st of manganese also was recycled to this end use in 1990.

CAST IRONS

Cast irons are used in a variety of applications. Some of the major end uses are as engine blocks, some types of gears, and large pieces of many different types of machinery. The flow model for cast irons is shown in figure 9. New feed material containing 2,559 st of manganese went to processing. Obsolete scrap containing 13,467 st of manganese, prompt scrap containing 8,978 st of manganese, and home scrap containing 17,645 st of manganese were also part of the feed to processing. During processing, material containing 10,662 st of manganese reported to processing losses. Material containing 14,341 st of manganese was feed to manufacturing.

During manufacturing, material containing 224 st of manganese reported as manufacturing losses, and prompt scrap containing 8,978 st of manganese was produced and recycled back to processing. Final products contained 5,139 st of manganese.

Figure 8



Unspecified steels flow model, 1990; amounts are in short tons.

Typically, today's automobiles last an average of 10 years (18). Because automobile engine parts are the heaviest users of cast irons, a life span of 10 years is assumed. Thus, potentially available obsolete scrap for 1990 production would come from 1980 apparent consumption of manganese in cast irons. Thus, obsolete scrap containing 26,492 st of manganese potentially would be available for consumption in 1990. This material is not recycled for its manganese content, but for its iron content. Production losses in 1980 contained 17,995 st of manganese. The remaining products would then become obsolete scrap in 1990. Scrap containing 8,497 st of manganese was available for recovery in 1990. The major loss of material would be in a recycling loss of 10 pct, or 850 st of manganese. This would leave recyclable material containing 7,647 st of manganese. An additional portion of manganese-bearing scrap containing 5,820 st of manganese from other end uses (possibly as downgraded steel scrap) is added to give 13,467 st of manganese in recycled obsolete scrap.

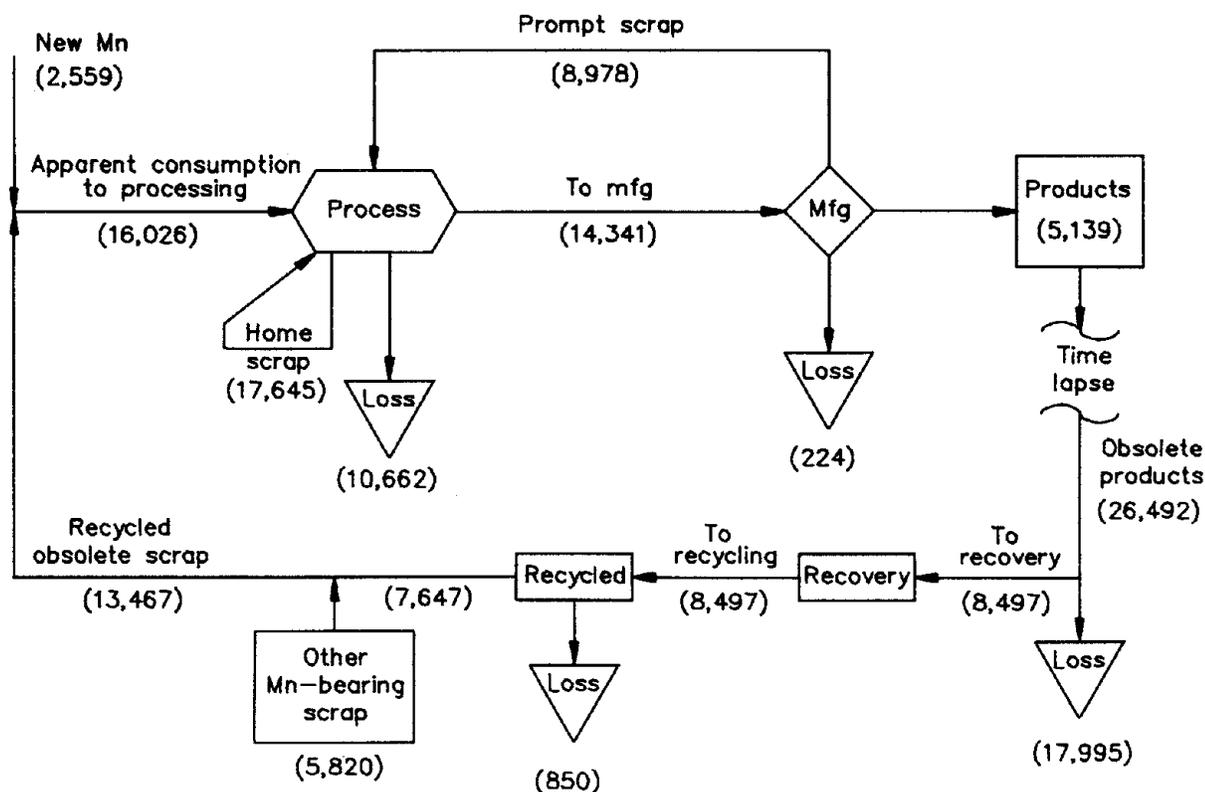
SUPERALLOYS

Superalloys are metals that have very high strengths and that are resistant to corrosion and high temperatures.

Because of their high values (up to \$31/kg or \$14/lb), much emphasis is placed on recycling these materials. Typical uses are in jet aircraft engine components, both moving and stationary parts. A number of these alloys are also used for applications in highly corrosive environments. Typically, superalloys are nickel- and cobalt-based alloys, but there are also some iron-based superalloys. The flow model for manganese in superalloys is shown in figure 10. Processing feed materials included new material containing 198 st of manganese, 41 st of manganese in obsolete scrap, 81 st of manganese in prompt scrap, and 224 st of manganese in home scrap. During processing, material containing 4 st of manganese reported as processing losses, and material containing 7 st of manganese reported to downgraded scrap. Processed metal feed to manufacturing contained 308 st of manganese.

During manufacturing, material containing 26 st of manganese reported to manufacturing losses, and scrap containing 33 st of manganese reported to downgraded scrap. Prompt scrap containing 111 st of manganese also was produced. Part of this prompt scrap, containing 30 st of manganese, was exported. The remaining prompt scrap, containing 81 st of manganese, was recycled to processing. Final products contained 139 st of manganese.

Figure 9



Cast irons flow model, 1990; amounts are in short tons.

Material from 1985 apparent consumption of manganese in superalloys contained 414 st of manganese and is potentially available for recycling. Production losses in 1985 claimed 173 st of contained manganese. During recovery, scrap containing 195 st of manganese reported to unknown and unrecovered losses. Of the obsolete scrap going on to processing, material containing 5 st of manganese reported to recycling losses, and scrap containing 41 st of manganese was recycled. Thus, scrap and waste containing about 373 st of manganese, as well as chromium, cobalt, and nickel, are lost to efficient recycle. This would amount to about 1-1/2 times the 1990 apparent consumption of manganese in superalloys.

Data shown by Papp give an estimated breakdown of the various scrap and loss components in the flow model for superalloys for 1990 (27) (table 4). Note that the prompt scrap that was exported contained mostly grindings and turnings (69 pct), which frequently are not suitable for recycle back to vacuum-melted superalloys because of possible contamination. All 30 st of manganese in the exported prompt scrap is lost to domestic production of superalloys, which contain chromium, cobalt, and manganese—strategic and critical materials. Total losses of superalloys to wastes, downgraded scrap, and export (405 st contained manganese) amounted to about

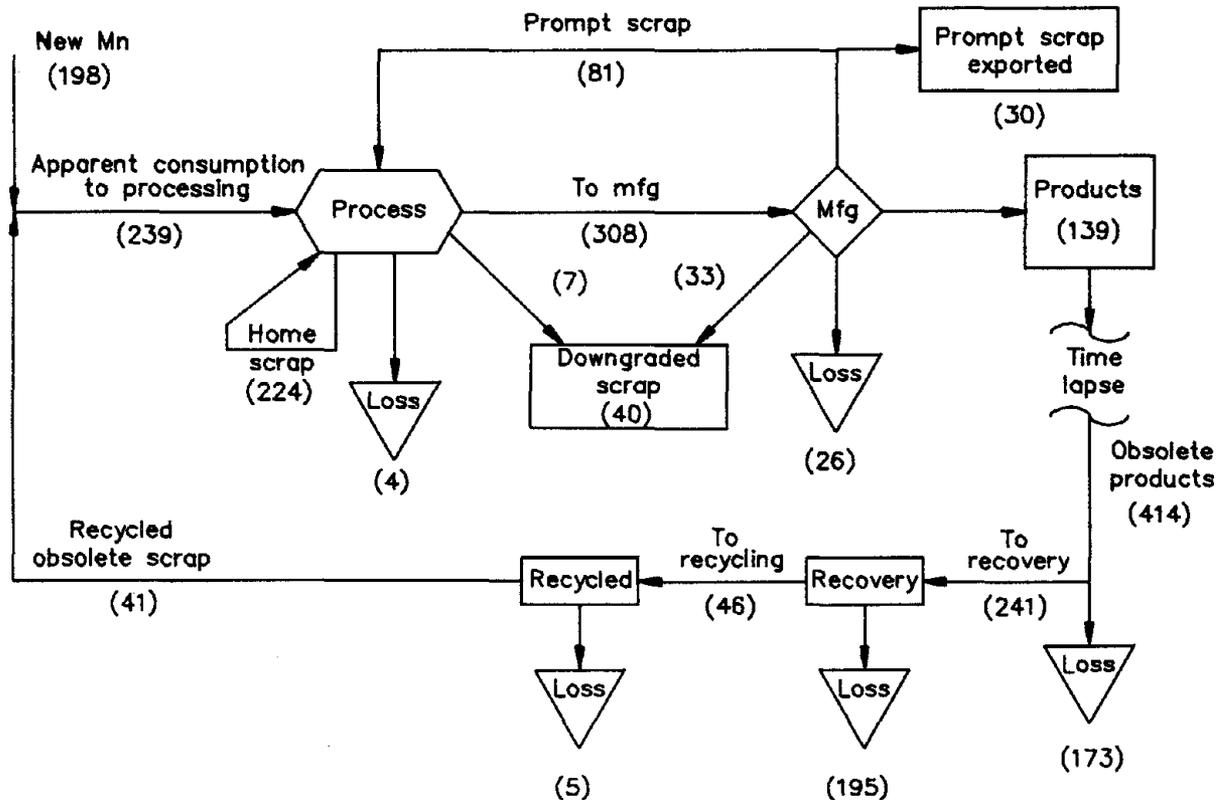
double the 1990 apparent consumption of manganese in superalloys.

OTHER ALLOYS

Materials in this industry are aluminum alloys, copper alloys, nickel alloys, and various other alloys, in the majority of which manganese is present as a minor component. These materials are used in a wide variety of applications: aluminum alloys for beverage containers and marine, automobile, and aircraft parts; copper alloys for switches, circuit breakers, continuous casting molds, heat exchanger tubes and pipe; nickel alloy for seawater corrosion resistance; and miscellaneous other products, depending on the alloy in question.

The flow model for other alloys is shown in figure 11. Processing feed consisted of new materials containing 17,638 st of manganese, prompt scrap containing 4,380 st of manganese, home scrap containing 5,328 st of manganese, and obsolete scrap containing 8,648 st of manganese. During processing, material containing 4,501 st of manganese reported to processing losses, and the remaining materials, containing 26,171 st of manganese, reported as feed for manufacturing.

Figure 10



Superalloys flow model, 1990; amounts are in short tons.

Table 4.—Composition of superalloy scrap and loss fractions in 1990

Fraction	Contained Mn, st
Home scrap:	
Grindings	6
Mixed scrap	13
Solid scrap	181
Turnings	24
Total	224
Processing losses: Dust	4
Processing-downgraded scrap:	
Grindings	3
Mixed scrap	4
Total	7
Manufacturing prompt scrap exports:	
Grindings	9
Solid scrap	8
Turnings	12
Unknown	2
Total	¹ 30
Manufacturing prompt scrap to processing:	
Solids	57
Turnings	24
Total	81
Manufacturing-downgraded scrap:	
Grindings	10
Solid scrap	8
Turnings	13
Unknown	2
Total	33
Manufacturing losses (waste):	
Grindings	5
Waste	20
Unknown	2
Total	¹ 26

¹Numbers do not add to total shown because of independent rounding.

During manufacturing, prompt scrap containing 4,380 st of manganese and manufacturing loss material containing 410 st of manganese were produced. The remaining material was in final products containing 21,381 st of manganese.

These products are assumed to have a 10-year use life (18). Thus, the 1980 apparent consumption of manganese in other alloys was potentially available for recycling and contained 26,286 st of manganese. However, this material is not known to be recycled solely for its manganese content, but is recycled rather for its base metal content.

During production, material containing 4,911 st of manganese was lost. Unknown and unrecovered losses

accounted for an additional 11,766 st of contained manganese. During recycling, additional material containing 961 st of manganese was lost, leaving recycled obsolete scrap containing 8,648 st of manganese for new production.

MISCELLANEOUS AND UNSPECIFIED MATERIALS

This category encompasses small metallurgical end uses of manganese, including the consumption of an unknown quantity of material in which high-carbon ferromanganese is used to produce superalloys, and medium- and low-carbon ferromanganese and silicomanganese are used to produce other alloys. (The amount of these materials in those end uses is withheld to avoid disclosing company proprietary data.) The flow model for this category of material is a metallurgical model because most of the materials in this group are metals (figure 12). Processing feed included new material containing 7,245 st of manganese, obsolete scrap containing 2,409 st of manganese, prompt scrap containing 1,612 st of manganese, and home scrap containing 1,959 st of manganese. During processing, material containing 1,659 st of manganese reported to processing losses, and material containing 474 st of manganese reported to downgraded scrap. Processing material feed to manufacturing contained 9,133 st of manganese.

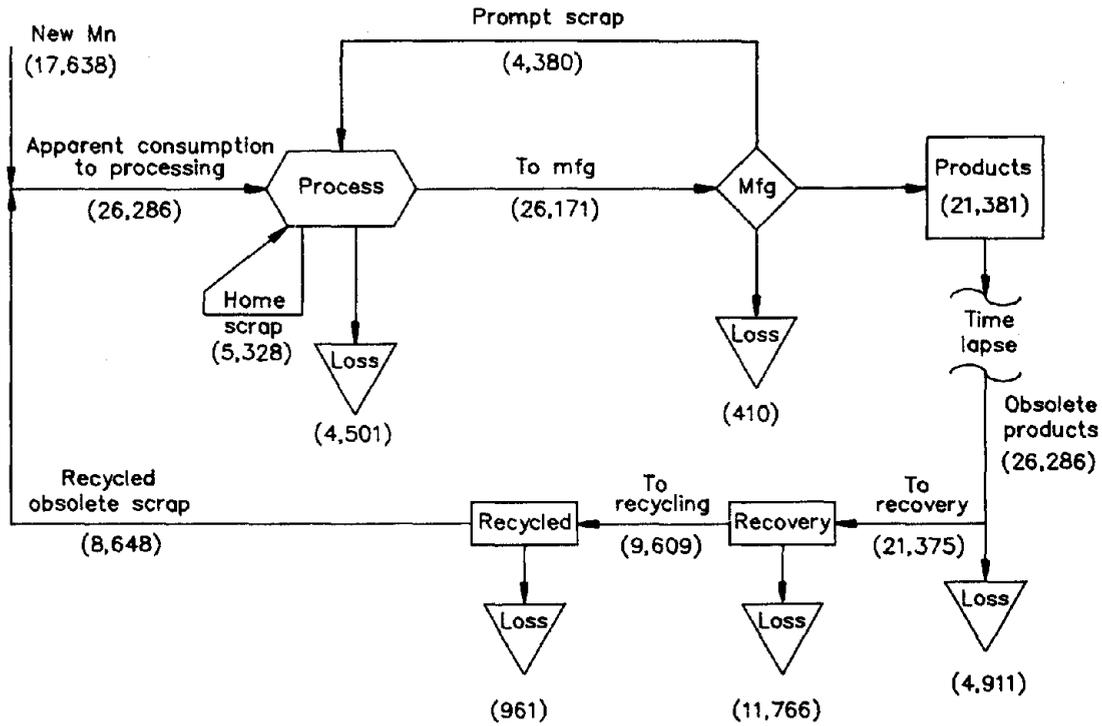
During manufacturing, material containing 1,612 st of manganese reported as prompt scrap, material containing 1,438 st of manganese reported to downgraded scrap, and material containing 142 st of manganese reported to manufacturing losses. The final products contained 5,941 st of manganese.

Material from 1985 apparent consumption of manganese in miscellaneous and unspecified materials potentially available for recycle contained 12,210 st of manganese. Production loss material contained 4,696 st of manganese. Unknown and unrecovered losses accounted for 4,837 st of contained manganese, and recycling losses accounted for an additional 268 st of contained manganese. Obsolete scrap recycled contained 2,409 st of manganese.

CHEMICALS

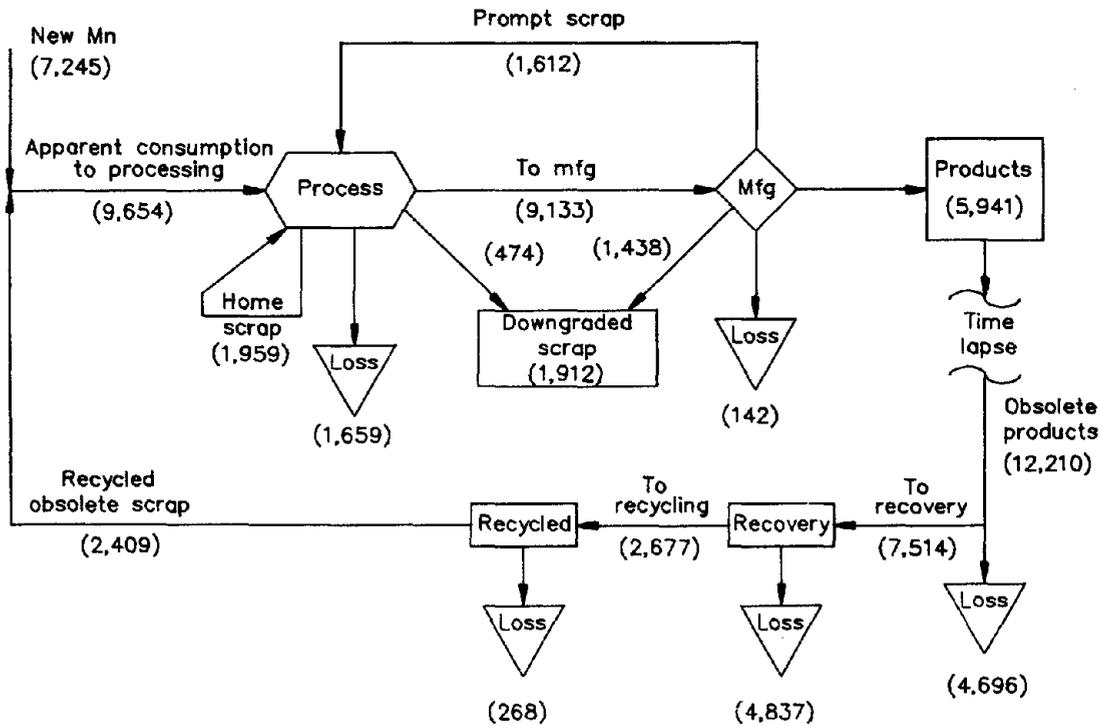
Manganese chemicals are used for oxidation, water treatment, and a number of other purposes. The flow model for manganese chemicals is shown in figure 13. Chemical processing consumed new material containing 40,000 st of manganese in 1990. During processing, material containing 1,200 st of manganese reported to

Figure 11



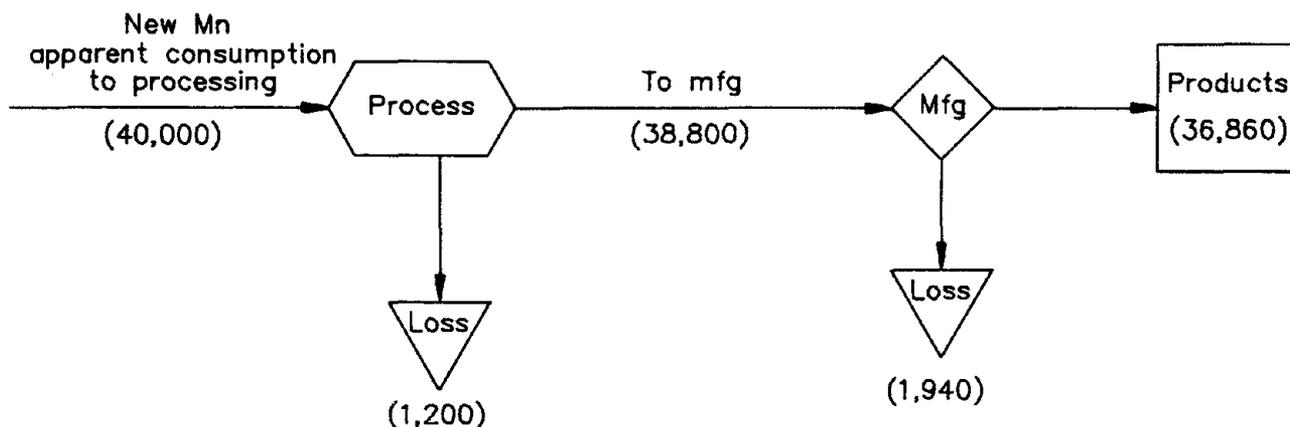
Other alloys flow model, 1990; amounts are in short tons.

Figure 12



Miscellaneous and unspecified materials flow model, 1990; amounts are in short tons.

Figure 13



Chemicals flow model, 1990; amounts are in short tons.

processing losses. The remaining material reported to chemical manufacturing and contained 38,800 st of manganese. During manufacturing of manganese chemicals, material containing 1,940 st of manganese reported to manufacturing losses. The final chemical products contained 36,860 st of manganese.

Manganese chemicals, like most chemicals, are employed in dissipative end uses. Thus, the manganese content is not readily available for recycle.

BATTERIES

Manganese has long been used in zinc-carbon dry cell batteries. New manganese, ultimately in the form of manganese dioxide containing 46,000 st of manganese, was consumed by the battery industry in 1990. The flow model for manganese in batteries is shown in figure 14. During processing of the material, 1,380 st of contained manganese reported as processing losses. Processed material containing 44,620 st of manganese went as feed to manufacturing. During manufacturing, material containing 2,231 st of manganese reported as manufacturing losses, and material containing 42,389 st of manganese reported in the final products. No economical method for recycling the manganese in batteries has been found to date.

OVERALL MANGANESE INDUSTRY

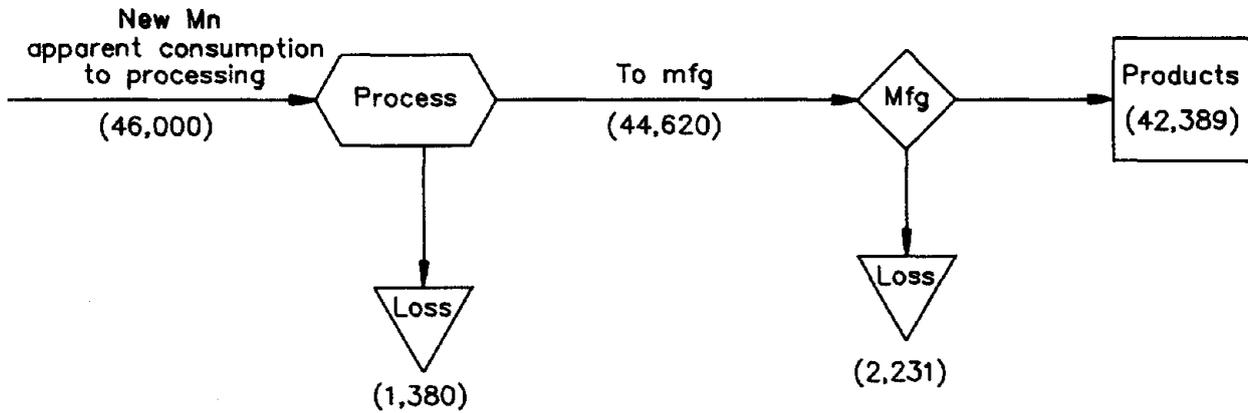
This is a composite flow model summed from the values in all manganese industry flow models described above. The flow model is shown in figure 15. Processing feed consists of new manganese material containing 606,413 st of manganese, recycled obsolete scrap

containing 81,799 st of manganese, prompt scrap containing 37,722 st of manganese, and home scrap containing 99,274 st of manganese. Material reporting to processing losses contained 342,562 st of manganese, and material reporting to processing downgraded scrap contained 28,135 st of manganese. The remaining material, containing 355,240 st of manganese, reported as processing feed to manufacturing.

During manufacturing, prompt scrap containing 37,752 st of manganese was produced. Superalloy prompt scrap containing 30 st of manganese was exported, and the remaining prompt scrap, containing 37,722 st of manganese, went to processing. In addition, manufacturing-downgraded scrap containing 36,144 st of manganese and manufacturing loss material containing 38,344 st of manganese were produced. Final products contained 243,001 st of manganese.

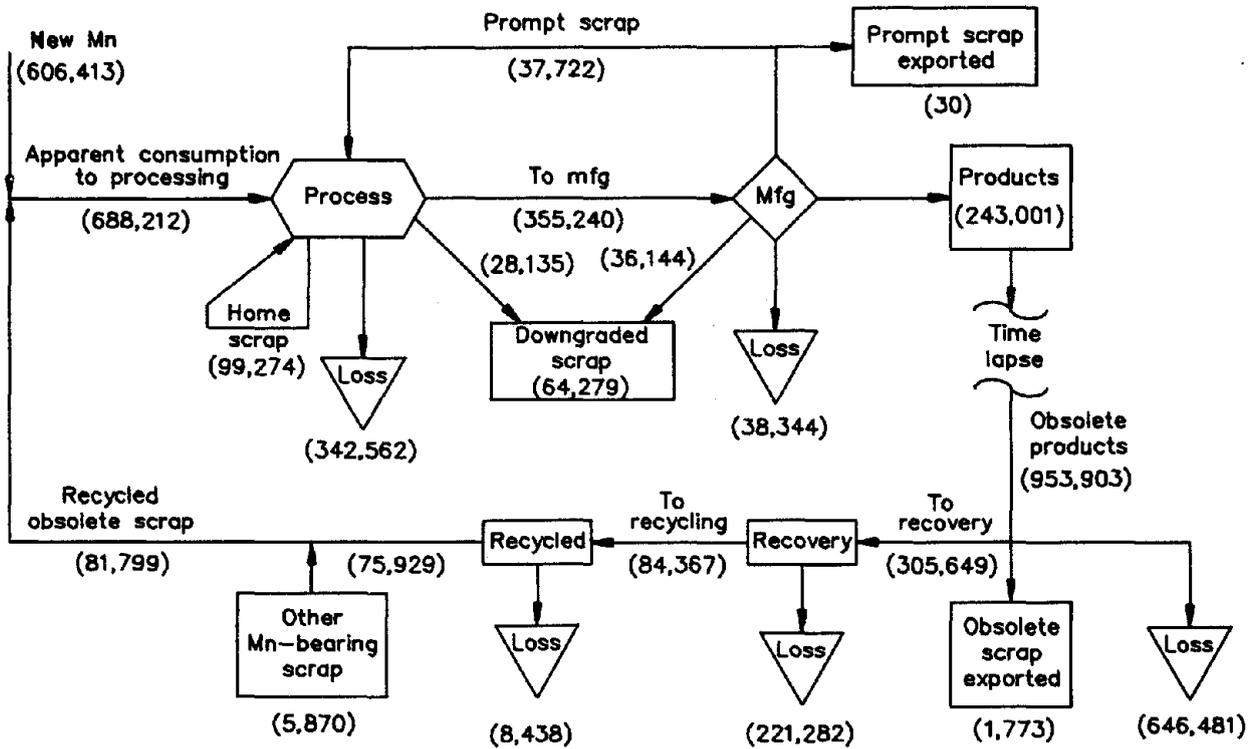
Potentially available obsolete materials for recovery and recycle contained 953,903 st of manganese, an amount equal to about 1.4 times the 1990 apparent consumption of manganese. Of this potentially available material, material containing 1,773 st of manganese was exported. Production losses accounted for 646,481 st of manganese. Unknown and unrecovered losses contained 221,282 st of manganese, and recycling losses contained 8,438 st of manganese. Recycled obsolete scrap contained 81,799 st of manganese. This is about 8 pct of the material potentially available for recycle and accounts for 12 pct of 1990 apparent consumption. The low level of recycled manganese was because of the unfavorable economics of recovering manganese from steel slags, the principal destination of steelmaking process losses.

Figure 14



Batteries flow model, 1990; amounts are in short tons.

Figure 15



Overall manganese industry flow model, 1990; amounts are in short tons.

SUMMARY

A commodity flow model was developed for the industries that consume manganese. Based on available data, the model follows manganese through its processing, manufacturing, and recycling operations, showing estimated values for material lost through these operations. The model was developed using certain estimates and assumptions and the best data available at the time. The model can be updated easily as new data become available. The multiplication factors will all change with time. New factors can replace older ones as data are acquired.

An industry flowchart was presented for each of the industries that consume manganese. The overall flow of the manganese commodity was also presented. The apparent consumption of manganese in 1990 was 695,000 st, which includes ferroalloy production losses. The estimated amounts of contained manganese consumed by the various industries are shown in table 2: the metallurgical industries—609,000 st (about 88 pct of 1990 apparent consumption), the chemical industry—40,000 st (about 6 pct), and the battery industry—46,000 st (about 7 pct). Of the metallurgical industries' consumption, approximately 69 pct went to carbon steels (about 61 pct of the total 1990 apparent consumption). The next three highest consumers of manganese were the full alloy steels industry—61,988 st (9 pct of total 1990 apparent consumption), the battery industry, and the chemical industry. All other metallurgical industries combined equaled 18 pct.

Based on the estimated life spans of the various products and the estimated amounts consumed in 1980 (10 years), 1985 (5 years), and 1990 (same year), there were potentially recyclable products containing 953,903 st of manganese (figure 15). Recycled obsolete scrap contained 81,799 st of manganese, or 12 pct of the 1990 apparent consumption of manganese. There currently is

no means of accurately tracing how much manganese-bearing steel scrap is actually recycled to the same end use or another manganese-consuming end use.

The 10 highest loss areas for manganese in 1990 accounted for 88 pct of the total losses during processing, manufacturing, and recycling (table 5). The industry with the biggest loss was the carbon steel industry. Carbon steel processing losses, processing-downgraded scrap, manufacturing losses, manufacturing-downgraded scrap, unknown and unrecovered losses in recovery, and recycling losses amounted to an estimated 435,960 st of contained manganese and accounted for 72 pct of total manganese losses in 1990. Most other losses of 2 pct and more were in the iron and steel industries.

Table 5.—Loss materials for manganese in 1990

Category	Contained Mn, st	Pct of total
Carbon steel processing losses	247,996	41
Obsolete carbon steel unknown and unrecovered losses	113,508	19
Full alloy steel processing losses	36,421	6
Carbon steel manufacturing-downgraded scrap	26,617	4
Carbon steel manufacturing losses	26,617	4
HSLA steel processing losses	22,987	4
Carbon steel processing-downgraded scrap	21,222	4
SHR processing losses	13,548	2
Obsolete other alloys unknown and unrecovered losses	11,766	2
Cast iron processing losses	10,662	2
All others	72,901	12
Total	604,245	100

CONCLUSIONS

A manganese flow model has been developed. The mathematical relationships in the model are discussed in the appendix. The model estimates the distribution of 695,000 st of manganese consumed in the 12 manganese-consuming industries. Initially, 6,786 st of manganese was lost in domestic ferromanganese and metal production. The best available data estimate that about 445,185 st of manganese was lost during processing and manufacturing operations: 380,906 st to waste and 64,279 st to downgraded scrap. The 37,722 st of manganese in prompt scrap

that was produced during manufacturing and the 99,274 st of manganese in home scrap that was generated during processing were efficiently recycled. Of the obsolete material potentially available for recycling, estimated with current available data, only the disposition of about 81,799 st of manganese to recycling can be followed. Obsolete materials containing 646,481 st of manganese reported to production losses. Obsolete material, mostly SHR steel scrap and superalloy scrap, containing 1,773 st of manganese was known to be exported. The remaining

obsolete material, containing 221,282 st of manganese as unknown, unrecovered, use-life, or dissipative losses, cannot be traced with current data. There is a need to obtain data that trace where this material goes. Thus, it is recommended that the USBM make changes in its

data-gathering survey sheets to obtain the missing information on a continuing basis. This would provide a continuously up-to-date flow model that can be supplied to those requiring the information in developing national policy regarding strategic and critical materials.

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APPENDIX¹

This section discusses the assumptions and mathematical relationships that were used to make the best estimates of consumption, losses, downgrading, and recycling in the manganese industry in 1990.

Consumption

In the manganese chapter of the 1991 Minerals Yearbook, v. 1, Jones (28) stated that the 1990 total apparent consumption of manganese in the United States was 695,000 st and that 1990 apparent consumption of manganese in the battery and chemical industries was 46,000 st and 40,000 st, respectively.

Then $A = B - C - D,$ (A-1)

where $A = 1990$ estimated apparent consumption of manganese in the metallurgical industries,

$B = 1990$ total apparent consumption of manganese (28),

$C = 1990$ apparent consumption of manganese in batteries (28),

and $D = 1990$ apparent consumption of manganese in chemicals (28).

Therefore, $A = 695,000 - 46,000 - 40,000$
 $= 609,000$ st of manganese consumed in metallurgical end uses in 1990.

Jones (28) also stated that January 1, 1990, industry stocks of manganese contained 324,000 st of manganese and the December 31, 1990, industry stocks of manganese contained 266,000 st of manganese, while materials containing 22,000 st of manganese were shipped to industry in 1990 from Government stockpile excesses.

$$E = F - G, \quad (A-2)$$

where $E = 1990$ consumption of manganese from industry stocks,

$F = 1990$ January 1, 1990, stocks of manganese (28),

and $G = 1990$ December 31, 1990, stocks of manganese (28).

Therefore, $E = 324,000 - 266,000$
 $= 58,000$ st of manganese consumed from industry stocks.

Then $H = E + I,$ (A-3)

where $H =$ manganese in total inventory consumed in 1990,

and $I =$ manganese in material shipped to industry from Government stockpiles (28).

Therefore, $H = 58,000 + 22,000$
 $= 80,000$ st of manganese consumed from stocks.

Then $J = K - L,$ (A-4)

where $J =$ manganese in difference of manganese imports and exports of metal and alloys,

$K =$ manganese imports (28),

and $L =$ manganese exports (28).

Therefore, $J = 505,000 - 14,000$
 $= 491,000$ st of manganese consumed from imports minus exports of metals and alloys.

Then $M = N - O,$ (A-5)

where $M =$ manganese from the difference of imports and exports of ore,

$N =$ manganese in ore imports (28),

and $O =$ manganese in ore exports (28).

Therefore, $M = 169,000 - 46,000$
 $= 123,000$ st of manganese in consumption from the difference in imports and exports.

¹Unless otherwise stated, all manganese quantities are short tons of contained manganese.

Then $P = J + M,$ (A-6)

where $P =$ total manganese consumption from difference in imports and exports.

Therefore, $P = 491,000 + 123,000$
 $= 614,000$ st of manganese consumed from net foreign trade.

Now $Q = J/P,$ (A-7)

where $Q =$ fraction from metals and alloys.

$$Q = 491,000/614,000$$

$$= 0.80,$$

and $R = M/P,$ (A-8)

where $R =$ fraction from ores.

$$R = 123,000/614,000$$

$$= 0.20.$$

Assuming that consumption from stocks has the same ratio of alloy and metal to ore,

then $S = H \times Q,$ (A-9)

where $S =$ manganese in stocks of alloy and metal.

$$S = 80,000 \times 0.80$$

$$= 64,000$$
 st of manganese from stocks of alloy and metal.

Then $T = H \times R,$ (A-10)

where $T =$ manganese in ore stocks.

$$T = 80,000 \times 0.20$$

$$= 16,000$$
 st of manganese from stocks of ore.

Then $U = J + S,$ (A-11)

where $U =$ total manganese from metal and alloy consumed from net foreign trade and stocks.

$$U = 491,000 + 64,000$$

$= 555,000$ st total manganese from metal and alloy.

Then $V = A - U,$ (A-12)

where $V =$ estimated manganese in U.S.-produced metal and alloy.

$$V = 609,000 - 555,000$$

$= 54,000$ st of manganese in U.S.-produced metal and alloy, and that from stocks.

Metal imports of manganese in 1990 were 14,279 st (I).
 Metal exports of manganese in 1990 were 6,773 st (I).

Now $W = Y - Z,$ (A-13)

where $W =$ estimated manganese metal consumed from foreign trade,

$Y =$ 1990 manganese metal imports,

and $Z =$ 1990 manganese metal exports.

Therefore, $W = 14,279 - 6,773$

$= 7,506$ st manganese metal estimates as consumed from foreign trade.

The 1990 reported consumption of manganese metal in metallurgical end uses was 25,424 st of contained manganese (I).

Then $AA = AB - W,$ (A-14)

where $AA =$ estimated U.S.-produced manganese metal,

and $AB =$ 1990 reported consumption of manganese metal.

Therefore, $AA = 25,424 - 7,506$

$= 17,918$ st of manganese estimated as U.S.-produced metal.

Then $AC = V - AA,$ (A-15)

where AC = estimated U.S.-produced ferromanganese and silicomanganese.

$$\begin{aligned} AC &= 54,000 - 17,918 \\ &= 36,082 \text{ st of manganese estimated in U.S. ferromanganese and silicomanganese.} \end{aligned}$$

Now it has been established that U.S.-produced manganese alloys contained an estimated 36,082 st of manganese and U.S.-produced manganese metal contained an estimated 17,918 st of manganese. Jones (1) reported for 1990 that 357,000 st of manganese was consumed as ferromanganese and that a reported 71,000 st of manganese was consumed as silicomanganese.

Then $AD = AE + AF,$ (A-16)

where AD = manganese reported consumed as ferromanganese and silicomanganese,

AE = manganese reported consumed as ferromanganese (1),

and AF = manganese reported consumed as silicomanganese (1).

Therefore, $AD = 357,000 + 71,000$
 $= 428,000$ st of manganese reported consumed as ferromanganese and silicomanganese.

Then $AG = AE/AD,$ (A-17)

where AG = fraction reported consumed as ferromanganese.

$$\begin{aligned} AG &= 357,000/428,000 \\ &= 0.83411. \end{aligned}$$

Then $AH = AF/AD,$ (A-18)

where AH = fraction reported consumed as silicomanganese.

$$\begin{aligned} AH &= 71,000/428,000 \\ &= 0.16589. \end{aligned}$$

Assuming the same fractions hold for U.S.-produced ferromanganese and silicomanganese,

then $AI = AC \times AG,$ (A-19)

where AI = estimated manganese contained in U.S.-produced ferromanganese.

$$\begin{aligned} AI &= 36,082 \times 0.83411 \\ &= 30,096 \text{ st of manganese estimated to be in U.S.-produced ferromanganese,} \end{aligned}$$

and $AJ = AC \times AH,$ (A-20)

where $AJ = 36,082 \times 0.16589$
 $= 5,986$ st of manganese estimated to be in U.S.-produced silicomanganese.

Manganese in Slag²

During the production of ferromanganese, 240 kg of slag—containing 525,000 ppm of manganese per metric ton of ferromanganese produced—and 164.8 kg of sludge—containing 20,000 ppm of manganese—were estimated to be generated (29).

Then $AK = AI \times 0.907185,$ (A-21)

where AK = manganese in U.S.-produced ferromanganese, t,

and 0.907185 = metric ton per short ton.

Therefore, $AK = 30,096 \times 0.907185$
 $= 27,303$ t manganese estimated to be in U.S.-produced ferromanganese.

Then $AL = AK/0.778,$ (A-22)

where AL = estimated ferromanganese produced in the United States in 1990, t,

and 0.778 = fraction of manganese in ferromanganese (30).

²Both metric tons and equivalent short tons are used in this section because values were reported in metric units (29).

Therefore, $AL = 27,303/0.778$
 $= 35,094$ t of ferromanganese estimated
to be produced in the United States
in 1990.

Then $AM = AN \times AL \times AO/1,000$, (A-23)

where $AM =$ manganese in slag produced in United
States in 1990 during ferromanga-
nese production, t,

$AN =$ generation factor (240 kg/t) (29),

$AO =$ concentration of manganese in slag
(29),

and $1,000 =$ kilograms per metric ton.

Therefore, $AM = 240 \times 35,094 \times (525,000/1,000,000)/$
 $1,000$
 $= 4,422$ t of manganese in slag produced
during U.S. ferromanganese pro-
duction.

Then $AP = AM/0.907185$, (A-24)

where $AP =$ manganese in slag produced during
U.S. ferromanganese production, st,

and $0.907185 =$ metric ton per short ton

$= 4,422/0.907185$.

Therefore, $AP = 4,874$ st of manganese in slag pro-
duced during U.S. ferromanganese
production.

Then $AQ = AR \times AL \times AS/1,000$, (A-25)

where $AQ =$ manganese in sludge produced in the
United States in 1990 during fer-
romanganese production, t,

$AR =$ generation factor (164.8 kg/t) (29),

$AS =$ concentration of manganese in sludge,
(29),

and $1,000 =$ kilograms per metric ton.

Therefore, $AQ = 164.8 \times 35,094 \times (20,000/1,000,000)/$
 $1,000$

$= 116$ t manganese in sludge.

Then $AT = AQ/0.907185$, (A-26)

where $AT =$ manganese in sludge, st,

and $0.907185 =$ metric ton per short ton.

Therefore, $AT = 116/0.907185$

$= 128$ st of manganese in sludge during
1990 U.S. ferromanganese produc-
tion.

During the production of silicomanganese, 1,100 kg of
slag—containing 70,000 ppm of manganese per metric ton
of silicomanganese produced—and 98.5 kg of sludge—
containing 200,000 ppm of manganese per metric ton of
silicomanganese produced—were estimated to be generated
(29).

Then $AU = AJ \times 0.907185$, (A-27)

where $AU =$ estimated manganese in U.S.-pro-
duced silicomanganese in 1990, t,

and $0.907185 =$ metric ton per short ton.

Therefore, $AU = 5,986 \times 0.907185$

$= 5,430$ t manganese estimated to be in
U.S.-produced silicomanganese in
1990.

Then $AV = AU/0.652$, (A-28)

where $AV =$ estimated silicomanganese produced,
t,

and $0.652 =$ average fraction of manganese in sil-
icomanganese (30).

Therefore, $AV = 5,430/0.652$

$= 8,328$ t of silicomanganese estimated
to be produced in the United States
in 1990.

Then $AW = AY \times AV \times AZ/1,000,$ (A-29)

where $AW =$ manganese in slag from silicomanganese production, t,

$AY =$ generation factor (1,100 kg/t of silicomanganese produced) (29),

$AZ =$ concentration of manganese in silicomanganese slag (28),

and 1,000 = kilograms per metric ton.

Therefore, $AW = 1,100 \times 8,328 \times (70,000/1,000,000)/1,000$
 $= 641$ t of manganese in slag from silicomanganese production.

Then $BA = AW/0.907185,$ (A-30)

where $BA =$ manganese in slag from silicomanganese production, st,

and 0.907185 = metric ton per short ton.

Therefore, $BA = 641/0.907185$
 $= 707$ st manganese in slag from silicomanganese production.

Then $BB = BC \times AV \times BD/1,000,$ (A-31)

where $BB =$ manganese in sludge from U.S. silicomanganese production in 1990, t,

$BC =$ generation factor (98.5 kg/t silicomanganese produced) (29),

$BD =$ concentration of manganese in sludge (29),

and 1,000 = kilograms per metric ton.

Therefore, $BB = 98.5 \times 8,328 \times (200,000/1,000,000)/1,000$
 $= 164$ t of manganese in sludge.

Then $BE = BB/0.907185,$ (A-32)

where $BE =$ manganese in sludge from silicomanganese production, st,

and 0.907185 = metric ton per short ton.

Therefore, $BE = 164/0.907185$

$= 181$ st of manganese in sludge.

Production Losses and Consumption

Assuming that 5 pct manganese is lost during electrolytic production of manganese from manganese sulfate,

then $BF = AA \times 0.05,$ (A-33)

where $BF =$ manganese lost during manganese metal production in the United States in 1990,

and $AA =$ U.S.-produced manganese metal.

Therefore, $BF = 17,918 \times 0.05$

$= 896$ st of manganese lost during manganese metal production in the United States in 1990.

Then $BG = AP + AT + BA + BE + BF,$ (A-34)

where $BG =$ manganese lost during 1990 U.S. production of ferromanganese, silicomanganese, and manganese metal,

$AP =$ manganese lost in slag during ferromanganese production,

$AT =$ manganese lost in sludge during ferromanganese production,

$BA =$ manganese lost in slag during silicomanganese production,

$BE =$ manganese lost in sludge during silicomanganese production,

and $BF =$ manganese lost during manganese metal production.

Therefore, $BG = 4,874 + 128 + 707 + 181 + 896$

$= 6,786$ st of manganese lost during 1990 U.S. production of ferromanganese, silicomanganese, and manganese metal.

Then $BH = AI + AJ + AA + BG,$ (A-35)

where $BH =$ manganese consumed in U.S. production of ferromanganese, silicomanganese, and manganese metal in 1990,

$AI =$ manganese in U.S.-produced ferromanganese,

$AJ =$ manganese in U.S.-produced silicomanganese,

and $AA =$ manganese in U.S.-produced manganese metal.

Therefore, $BH = 30,096 + 5,986 + 17,918 + 6,786$

$= 60,786$ st of manganese consumed in United States 1990 production of ferromanganese, silicomanganese and manganese metal.

Thus, 6,786 st of manganese in wastes was generated, and 54,000 st of manganese in alloys and metal was sent on to consuming industries.

Of the 609,000 st of manganese consumed for metallurgical end uses, 6,786 st of contained manganese went to wastes from U.S. production of manganese alloys and metal.

Then $BI = A - BG,$ (A-36)

where $BI =$ manganese in ferromanganese, silicomanganese, and manganese metal consumed in metallurgical industries,

and $A =$ U.S. apparent consumption of manganese in metallurgical end uses.

Therefore, $BI = 609,000 - 6,786$

$= 602,214$ st of manganese apparently consumed by the metallurgical industries.

Assuming that apparent consumption of manganese for each metallurgical consumption category is proportional to gross weight of reported consumption for each category,

then $BK_n = BL_n/BM,$ (A-37)

where $BK_n =$ fraction of ferromanganese, silicomanganese, or manganese metal reported consumed,

$BL_n =$ reported consumption of ferromanganese, silicomanganese, or manganese metal, gross weight,

and $BM =$ total reported consumption of ferromanganese, silicomanganese, and manganese metal, gross weight.

Results of using this equation are shown in table A-1.

Table A-1.—Reported manganese consumption in the metallurgical industry in 1990 by type of material consumed

End use	FeMn		SiMn		Mn metal	
	Gross wt, st	Fraction of total	Gross wt, st	Fraction of total	Gross wt, st	Fraction of total
Steels:						
Carbon	343,174	0.75364	74,121	0.68662	0	0.00000
SHR	13,897	0.03052	5,117	0.04740	3,101	0.12197
Full alloy	43,459	0.09552	18,013	0.16686	725	0.02852
HSLA	32,566	0.07152	5,969	0.05529	0	0.00000
Tool	262	0.00058	0	0.00000	46	0.00181
Unspecified	773	0.00170	231	0.00214	1,815	0.07139
Cast irons	13,938	0.03061	1,732	0.09583	0	0.00000
Superalloys	W	W	0	0.01604	180	0.00708
Other alloys ¹	950	0.00209	W	W	19,047	0.74917
Miscellaneous and unspecified materials	6,300	0.01384	2,767	0.02563	510	0.02006
Total	455,355	1.00000	107,950	1.00000	25,424	1.00000
Total Mn content	357,000	NAP	71,000	NAP	25,424	NAP

NAP Not applicable.

W Withheld.

¹Excludes alloy steels and superalloys.

Then $BN_n = BO \times BK_n$, (A-38)

where BN_n = amount of reported manganese consumed in end use,

and BO = total amount of reported manganese in metallurgical end uses.

Then BP = sum (of BN_n 's for ferromanganese, silicomanganese, and manganese metal in an end use), (A-39)

where BP = sum of gross weights of materials consumed in end uses.

Then $BQ_n = BN_n / (\text{sum of } BP\text{'s})$, (A-40)

where BQ_n = fraction of reported manganese in an end use.

Then $BR_n = BQ_n \times BS$, (A-41)

where BR_n = 1990 apparent consumption of manganese in an end use,

and BS = 1990 total apparent consumption of manganese in metallurgical end uses (31).

The results of applying equations A-38 to A-41 are shown in table A-2.

MATERIAL POTENTIALLY AVAILABLE FOR RECYCLING

Based on the literature data, SHR steels, full alloy steels, HSLA steels, tool steels, unspecified steels, superalloys, and miscellaneous and unspecified materials have an estimated life cycle of 5 years (5). Other alloys have an estimated life cycle of 10 years (5), and carbon steels and cast irons have a life cycle of 10 years (18). Thus, those materials available for consumption in 1990 that came from 5-year-old products would have come from 1985 production, while the 10-year-old products would have come from 1980 production.

1985 Production

Data from the 1985 Minerals Yearbook are shown in table A-3 (32). The reported amounts consumed and the total amount consumed in that form are used to calculate fractions consumed in an end use.

Table A-2.—Reported and apparent manganese consumption by the metallurgical industry in various end uses in 1990

End use	Estimated reported Mn consumption by source, st			Total reported consumption, st	Fraction of total reported consumption	Apparent consumption, st contained Mn
	FeMn	SiMn	Mn metal			
Steels:						
Carbon	269,050	48,750	0	317,800	0.70089	422,085
SHR	10,895	3,366	3,101	17,362	0.03829	23,059
Full alloy	34,100	11,847	725	46,673	0.10293	61,988
HSLA	25,532	3,926	0	29,458	0.06497	39,124
Tool	205	0	46	251	0.00055	334
Unspecified ¹	606	152	1,815	2,573	0.00567	3,417
Cast irons	10,927	1,139	0	12,067	0.02661	16,026
Superalloys	0	0	180	180	0.00040	239
Other alloys ²	745	0	19,047	19,792	0.04365	26,286
Miscellaneous and unspecified materials ³	4,939	1,820	510	7,269	0.01603	9,654
Total	357,000	71,000	25,424	453,424	1.00000	602,214

¹ Includes Mn metal in carbon steels; medium- and low-carbon FeMn in SHR steels; Mn metal in HSLA steels; all Mn alloys and metal in electric steel; and SiMn in tool steels.

² Excludes alloy steels and superalloys.

³ Includes high-carbon FeMn in superalloys and medium- and low-carbon FeMn and SiMn in other alloys.

It is first necessary to determine the amounts consumed in each category and reporting to final products in that category so that the potential amount of manganese available for recovery from obsolete scrap can be estimated.

$$\text{Now} \quad \text{RA} = \text{RB}/\text{RC}, \quad (\text{A-42})$$

where RA = fraction in that end use,

RB = reported amount of a form consumed in an end use,

and RC = reported total consumption of that form.

$$\text{Then} \quad \text{RD}_n = \text{RE}_n \times \text{RF}, \quad (\text{A-43})$$

where RD_n = reported consumption of a form in an end use,

RE_n = fraction of reported consumption, gross weight for a form in an end use,

and RF = total reported consumption, gross weight of that form.

The results of this equation are summarized in table A-4.

These results are shown in table A-3. It is assumed that the amount of contained manganese is also proportional to the fraction of consumed material, gross weight.

Table A-3.—Reported consumption for 1985 and fraction of manganese material by type of material consumed

End use	Reported consumption, st			Fraction of Mn		
	FeMn	SiMn	Mn metal	FeMn	SiMn	Mn metal
Steels:						
SHR	12,483	3,228	1,543	0.02681	0.03081	0.06297
Full alloy	34,379	13,653	908	0.07385	0.13030	0.03705
HSLA	34,206	5,642	626	0.07348	0.05385	0.02555
Tool	275	0	101	0.00059	0.00000	0.00412
Unspecified	692	660	61	0.00149	0.00630	0.00249
Superalloys	130	0	196	0.00028	0.00000	0.00800
Miscellaneous and unspecified materials	8,283	2,669	537	0.01779	0.02547	0.02191
Total metallurgical consumption	465,542	104,778	24,505	1.00000	1.00000	1.00000
Total Mn content	356,000	69,000	24,505	NAP	NAP	NAP

NAP Not applicable.

Table A-4.—Reported and apparent consumption of manganese forms in various end uses in 1985

(short tons of contained manganese)

End use	FeMn	SiMn	Mn metal	Consumption	
				Reported	Apparent
Steels:					
SHR	9,787	2,126	1,543	13,456	18,694
Full alloy	26,954	8,991	908	36,853	51,200
HSLA	26,819	3,715	626	31,160	43,291
Tool	216	0	101	317	440
Unspecified	543	435	61	1,038	1,442
Superalloys	102	0	196	298	414
Miscellaneous and unspecified materials	6,494	1,758	537	8,789	12,210

Then $BN_n = BO \times BK_n$, (A-38)

where BN_n = amount of reported manganese consumed in end use,

and BO = total amount of reported manganese in metallurgical end uses.

Then BP = sum (of BN_n 's for ferromanganese, silicomanganese, and manganese metal in an end use), (A-39)

where BP = sum of gross weights of materials consumed in end uses.

Then $BQ_n = BN_n / (\text{sum of } BP\text{'s})$, (A-40)

where BQ_n = fraction of reported manganese in an end use.

Then $BR_n = BQ_n \times BS$, (A-41)

where BR_n = 1990 apparent consumption of manganese in an end use,

and BS = 1990 total apparent consumption of manganese in metallurgical end uses (31).

The results of applying equations A-38 to A-41 are shown in table A-2.

MATERIAL POTENTIALLY AVAILABLE FOR RECYCLING

Based on the literature data, SHR steels, full alloy steels, HSLA steels, tool steels, unspecified steels, superalloys, and miscellaneous and unspecified materials have an estimated life cycle of 5 years (5). Other alloys have an estimated life cycle of 10 years (5), and carbon steels and cast irons have a life cycle of 10 years (18). Thus, those materials available for consumption in 1990 that came from 5-year-old products would have come from 1985 production, while the 10-year-old products would have come from 1980 production.

1985 Production

Data from the 1985 Minerals Yearbook are shown in table A-3 (32). The reported amounts consumed and the total amount consumed in that form are used to calculate fractions consumed in an end use.

Table A-2.—Reported and apparent manganese consumption by the metallurgical industry in various end uses in 1990

End use	Estimated reported Mn consumption by source, st			Total reported consumption, st	Fraction of total reported consumption	Apparent consumption, st contained Mn
	FeMn	SiMn	Mn metal			
Steels:						
Carbon	269,050	48,750	0	317,800	0.70089	422,085
SHR	10,895	3,366	3,101	17,362	0.03829	23,059
Full alloy	34,100	11,847	725	46,673	0.10293	61,988
HSLA	25,532	3,926	0	29,458	0.06497	39,124
Tool	205	0	46	251	0.00055	334
Unspecified ¹	606	152	1,815	2,573	0.00567	3,417
Cast irons	10,927	1,139	0	12,067	0.02661	16,026
Superalloys	0	0	180	180	0.00040	239
Other alloys ²	745	0	19,047	19,792	0.04365	26,286
Miscellaneous and unspecified materials ³	4,939	1,820	510	7,269	0.01603	9,654
Total	357,000	71,000	25,424	453,424	1.00000	602,214

¹ Includes Mn metal in carbon steels; medium- and low-carbon FeMn in SHR steels; Mn metal in HSLA steels; all Mn alloys and metal in electric steel; and SiMn in tool steels.

² Excludes alloy steels and superalloys.

³ Includes high-carbon FeMn in superalloys and medium- and low-carbon FeMn and SiMn in other alloys.

It is first necessary to determine the amounts consumed in each category and reporting to final products in that category so that the potential amount of manganese available for recovery from obsolete scrap can be estimated.

$$\text{Now} \quad RA = RB/RC, \quad (\text{A-42})$$

where RA = fraction in that end use,

RB = reported amount of a form consumed in an end use,

and RC = reported total consumption of that form.

$$\text{Then} \quad RD_n = RE_n \times RF, \quad (\text{A-43})$$

where RD_n = reported consumption of a form in an end use,

RE_n = fraction of reported consumption, gross weight for a form in an end use,

and RF = total reported consumption, gross weight of that form.

The results of this equation are summarized in table A-4.

These results are shown in table A-3. It is assumed that the amount of contained manganese is also proportional to the fraction of consumed material, gross weight.

Table A-3.—Reported consumption for 1985 and fraction of manganese material by type of material consumed

End use	Reported consumption, st			Fraction of Mn		
	FeMn	SiMn	Mn metal	FeMn	SiMn	Mn metal
Steels:						
SHR	12,483	3,228	1,543	0.02681	0.03081	0.06297
Full alloy	34,379	13,653	908	0.07385	0.13030	0.03705
HSLA	34,206	5,642	626	0.07348	0.05385	0.02555
Tool	275	0	101	0.00059	0.00000	0.00412
Unspecified	692	660	61	0.00149	0.00630	0.00249
Superalloys	130	0	196	0.00028	0.00000	0.00800
Miscellaneous and unspecified materials	8,283	2,669	537	0.01779	0.02547	0.02191
Total metallurgical consumption	465,542	104,778	24,505	1.00000	1.00000	1.00000
Total Mn content	356,000	69,000	24,505	NAp	NAp	NAp

NAp Not applicable.

Table A-4.—Reported and apparent consumption of manganese forms in various end uses in 1985

(short tons of contained manganese)

End use	FeMn	SiMn	Mn metal	Consumption	
				Reported	Apparent
Steels:					
SHR	9,787	2,126	1,543	13,456	18,694
Full alloy	26,954	8,991	908	36,853	51,200
HSLA	26,819	3,715	626	31,160	43,291
Tool	216	0	101	317	440
Unspecified	543	435	61	1,038	1,442
Superalloys	102	0	196	298	414
Miscellaneous and unspecified materials	6,494	1,758	537	8,789	12,210

The total 1985 apparent consumption of manganese is given as 698,000 st manganese (33). The 1985 apparent consumption was 39,000 st manganese for batteries and 22,000 st manganese for chemicals (33).

$$\text{Now} \quad \text{RG} = \text{RH} - \text{RI} - \text{RJ}, \quad (\text{A-44})$$

where RG = 1985 metallurgical apparent consumption,

RH = 1985 total apparent consumption of manganese,

RI = 1985 apparent consumption in batteries,

and RJ = 1985 apparent consumption in chemicals.

$$\begin{aligned} \text{Therefore, } \text{RG} &= 698,000 - 39,000 - 22,000 \\ &= 637,000 \text{ st of contained manganese in} \\ &\quad \text{metallurgical end uses.} \end{aligned}$$

The total reported metallurgical consumption of manganese was 458,505 st of contained manganese (32).

$$\text{Then} \quad \text{RK} = \text{RG}/\text{RL}, \quad (\text{A-45})$$

where RK = ratio of 1985 apparent metallurgical consumption to 1985 reported metallurgical consumption,

and RL = 1985 reported metallurgical consumption.

$$\begin{aligned} \text{Therefore, } \text{RK} &= 637,000/458,505 \\ &= 1.389298. \end{aligned}$$

It is assumed that the relative reported consumption in an end use is proportional to the apparent consumption in that end use.

$$\text{Then} \quad \text{RM}_n = \text{RN}_n \times \text{RK}, \quad (\text{A-46})$$

where RM_n = apparent consumption of manganese in an end use,

and RN_n = reported consumption of manganese in an end use.

The results of equation A-46 are shown in table A-4. The apparent consumption in 1985 is the material potentially available for recycling in 1990 from materials with a 5-year life cycle.

1980 Production

Those materials potentially available for recycling in 1990 for carbon steels, cast irons, and other alloys would come from 1980 apparent consumption of manganese in these end uses. The reported consumption of the various manganese forms in short ton gross weight for these end uses and the totals are given in table A-5 (34).

From the 1983 Minerals Yearbook chapter on manganese, the average manganese content in manganese ferroalloys was 78.356 pct, and in silicomanganese it was 66 pct (35). Another literature source shows that the average manganese content of spiegeleisen was 17.5 pct (36).

$$\text{Then} \quad \text{RO}_n = \text{RP}_n \times \text{RR}, \quad (\text{A-47})$$

where RO_n = reported consumption of a form in an end use, manganese content,

RP_n = reported consumption, gross weight of a form in an end use,

and RR = average manganese content of that form.

The results of equation A-47 are also shown in table A-5.

Table A-5.—Reported and apparent consumption of manganese forms in various end uses in 1980
(gross weight and manganese content in short tons)

End use	FeMn		SiMn		Mn metal ¹	Spiegeleisen		Consumption	
	Gross wt	Mn content	Gross wt	Mn content		Gross wt	Mn content	Reported	Apparent
Carbon steel . . .	595,577	466,670	92,196	60,849	5,706	301	53	533,278	687,434
Cast irons	16,367	12,825	11,695	7,719	8	0	0	20,551	26,492
Other alloys	2,025	1,587	2,576	1,700	14,112	2	0	17,399	22,429

¹Gross weight is same as Mn content.

The 1980 apparent consumption of batteries, and chemicals and the total apparent consumption are 17,000 st, 50,000 st, and 1,029,000 st of manganese, respectively (33). Chemicals and batteries are the only significant nonmetallurgical consumptions of manganese.

$$\text{Thus, } RS = RT - RU - RV, \quad (\text{A-48})$$

where RS = 1980 metallurgical apparent consumption of manganese,

RT = total 1980 apparent consumption of manganese,

RU = 1980 apparent consumption of manganese in batteries,

and RV = 1980 apparent consumption of manganese in chemicals.

$$\begin{aligned} \text{Therefore, } RS &= 1,029,000 - 17,000 - 50,000 \\ &= 962,000 \text{ st manganese in 1980 metallurgical apparent consumption.} \end{aligned}$$

Then the ratio of apparent consumption in 1980 to reported consumption in 1980 is determined as follows:

$$RW = RS/RX, \quad (\text{A-49})$$

where RW = ratio of apparent metallurgical consumption in 1980,

and RX = reported metallurgical consumption in 1980 $[(789,076 \times 0.78356) - (155,817 \times 0.66) - 25,092 - (303 \times 0.175)]$.

$$\begin{aligned} \text{Therefore, } RW &= 962,000/746,273 \\ &= 1.289072. \end{aligned}$$

Apparent consumption is assumed to be proportioned the same as reported consumption.

$$\text{Then } RY_n = RZ_n \times RW, \quad (\text{A-50})$$

where RY_n = 1980 apparent consumption of manganese in an end use,

RZ_n = 1980 reported consumption of manganese in an end use,

and RW = ratio of apparent consumption to reported consumption in 1980.

The results of equation A-50 are shown in table A-5.

ALL STEELS

During processing, only about one-third of added manganese reported in the finished steel. Most reported as slags, scrap, dusts, and sludges, principally the first (18). The fraction that reported to downgraded scrap was an amount equal to 0.05028 of the raw material feed. The raw material feed consisted of new manganese-containing material and obsolete scrap manganese-containing material. The latest data from 1985 estimated that the amount of new manganese plus manganese from scrap was 30.65 lb + 3.56 lb/st of steel, or 34.21 lb of manganese in raw material and scrap feed per short ton of steel produced (18).

$$\text{Then } BT = BU \times BV, \quad (\text{A-51})$$

where BT = amount of manganese in downgraded material,

BU = 34.21 lb/st of steel (raw material feed),

and BV = fraction of raw material feed that became processing-downgraded material.

$$\begin{aligned} \text{Therefore, } BT &= 34.21 \times 0.05028 \\ &= 1.72 \text{ lb of manganese per short ton of steel produced.} \end{aligned}$$

$$\text{Then } BW = BY - BT, \quad (\text{A-52})$$

where BW = pounds per short ton of steel produced that reported to processing losses,

and BY = total pounds of manganese per short ton of steel produced that were losses and downgraded material (18).

$$\begin{aligned} \text{Therefore, } BW &= 21.82 - 1.72 \\ &= 20.10. \end{aligned}$$

The flow data are shown in table A-6 (18). The fractions in table A-6 are used for all steels.

Table A-6.—Manganese flow during production of steels

Category	Mn content, lb/st of steel produced	Fraction of apparent consumption ¹
Input:		
New Mn	30.65	0.89594
Obsolete scrap	3.56	0.10406
Home scrap	4.61	0.13476
Prompt scrap	1.41	0.04122
Total	40.23	² 1.17597
Output:		
Processing losses	20.10	0.58755
Processing-downgraded scrap	1.72	0.05028
Home scrap	4.61	0.13476
Finished steel	13.8	0.40339
Total	40.23	² 1.17597

¹Apparent consumption equals new Mn and Mn in obsolete scrap.

²Numbers may not add to total shown because of independent rounding.

The fraction reporting to finished steel (processing feed to manufacturing) is calculated as follows:

$$TA = TB - TC - TD - TE, \quad (A-53)$$

where TA = fraction reporting to finished steel,

TB = fraction of total feed to processing (new manganese plus obsolete scrap plus home scrap plus prompt scrap),

TC = fraction to processing losses,

TD = fraction to processing-downgraded scrap,

and TE = fraction to home scrap.

$$\text{Therefore, } TA = (0.89594 + 0.10406 + 0.13476 + 0.04122) - 0.58755 - 0.05028 - 0.13476$$

$$= 0.40339.$$

CARBON STEELS

Carbon steels consumed 422,085 st of manganese in 1990. Carbon steels follow the flow model for all steels for processing operations. The fractions for each processing category are shown in table A-7. The 422,085 st of manganese is the manganese content of new material and purchased scrap. Also shown in table A-7 are the amounts of contained manganese in each category during processing of carbon steels.

Table A-7.—Processing fractions for carbon steels and contained manganese in each fraction

Category	Fraction	Contained Mn, st
Input:		
New Mn	0.89594	378,163
Obsolete scrap	0.10406	43,922
Home scrap	0.13476	56,880
Prompt scrap	0.04122	17,398
Total	1.17597	496,363
Output:		
Processing losses	0.58755	247,996
Processing-downgraded scrap ...	0.05028	21,222
Home scrap	0.13476	56,880
Processing feed to manufacturing	0.40339	170,265
Total	1.17597	496,363
Manufacturing output:		
Manufacturing-downgraded scrap	0.06306	26,617
Manufacturing losses	0.06306	26,617
Final products	0.23605	99,633

Manufacturing of products from finished steel is assumed to follow the flow sheet prepared for chromium (37).

$$\text{Then } CA = CB \times CC/CD, \quad (A-54)$$

where CA = fraction of apparent consumption reporting as manufacturing-downgraded scrap,

CB = fraction of processing feed to manufacturing,

CC = fraction reporting as downgraded scrap in the chromium (manganese) flow model (37),

and CD = fraction reporting as processing feed to manufacturing in the chromium (manganese) flow model (37).

$$\text{Therefore, } CA = 0.40339 \times 0.14776/0.94522$$

$$= 0.06306.$$

$$\text{Similarly } CE = CB \times CF/CD, \quad (A-55)$$

where CE = fraction of apparent consumption reporting as manufacturing losses,

and CF = fraction reporting as manufacturing losses in the chromium (manganese) flow model (37).

$$\begin{aligned} \text{Therefore, CE} &= 0.40339 \times 0.14776 / 0.94522 \\ &= 0.06306. \end{aligned}$$

$$\text{Then } CG = CB - CA - CE - CH, \quad (\text{A-56})$$

where CG = fraction of apparent consumption reporting as final products,

and CH = fraction of prompt scrap.

$$\begin{aligned} \text{Therefore, } CG &= 0.40339 - 0.06306 - 0.6306 - 0.04122 \\ &= 0.23605. \end{aligned}$$

$$\text{Now } CI_n = CJ_n \times CK, \quad (\text{A-57})$$

where CI_n = portion of manganese in each category,

CJ_n = fraction of apparent consumption in each category,

and CK = 1990 apparent consumption of manganese in carbon steels.

The results of equation A-57 are also shown in table A-7.

Carbon steel products are estimated to have a 10-year life cycle (18). Thus, obsolete scrap available for consumption in 1990 would come from 1980 apparent consumption of manganese in carbon steels. Apparent consumption of manganese in carbon steels in 1980 was estimated to be 687,434 st of contained manganese (32). Obsolete scrap containing an estimated 43,922 st of manganese was recycled to 1990 production. Literature sources show that about 10 pct of metal recovered is lost during recycling (27).

$$\text{Then } SA = SB \times 10/90, \quad (\text{A-58})$$

where SA = recycling losses,

SB = manganese recycled,

10 = percent of material lost in recycling (27),

and 90 = percent of material recycled (27).

$$\begin{aligned} \text{Therefore, } SA &= 43,922 \times 10/90 \\ &= 4,880 \text{ st of contained manganese.} \end{aligned}$$

$$\text{Then } SC = SB + SA, \quad (\text{A-59})$$

where SC = material recovered, contained manganese

$$= 43,992 + 4,880$$

= 48,802 st contained manganese in recovered obsolete scrap.

Assuming that losses and downgraded material fractions were the same as in 1990,

$$\text{then } SE_n = SF \times SG_n, \quad (\text{A-60})$$

where SE_n = manganese in loss or downgraded material,

SF = 1980 apparent consumption of manganese in carbon steels,

and SG_n = fraction reporting to that end use.

Using this equation results in the data shown in table A-8.

Table A-8.—Manganese in loss and downgraded scrap materials in 1980 for carbon steels

Category	Fraction	Contained Mn, st
Processing losses	0.58755	403,902
Processing-downgraded scrap . .	0.05028	34,564
Manufacturing-downgraded scrap	0.06306	43,329
Manufacturing losses	0.06306	43,329
Total	0.76389	525,124

$$\text{Then } SH = SF - SI, \quad (\text{A-61})$$

where SH = amount of manganese in 1980 final products,

and SI = amount of manganese in 1980 production losses.

$$\begin{aligned} \text{Therefore, } SH &= 687,434 - 525,124 \\ &= 162,310 \text{ st of manganese in 1980 final products.} \end{aligned}$$

$$\text{Then } SJ = SH - SC, \quad (\text{A-62})$$

where SJ = manganese in unknown and unrecovered losses.

$$\begin{aligned} SJ &= 162,310 - 48,802 \\ &= 113,508 \text{ st of manganese in unknown and unrecovered losses.} \end{aligned}$$

STAINLESS AND HEAT-RESISTANT STEELS

SHR steels follow the flow model for all steels for processing operations. The fractions and amounts of manganese for each processing category are shown in table A-9.

Table A-9.—Flow of manganese in SHR steels in 1990

Category	Fraction	Contained Mn, st
New Mn	0.89594	20,659
Obsolete scrap	0.10406	2,400
1990 apparent consumption	1.00000	23,059
Prompt scrap	0.04122	950
Home scrap	0.13476	3,107
Processing losses	0.58755	13,548
Processing-downgraded scrap	0.05028	1,159
Processing feed to manufacturing ..	0.40339	9,302
Manufacturing-downgraded scrap ...	0.06275	1,447
Manufacturing losses	0.00627	145
Final products	0.29315	6,760

Then $SN = SO \times SP/SQ$, (A-63)

where SN = fraction of 1990 apparent consumption reporting as manufacturing-downgraded scrap,

SO = fraction of processing feed to manufacturing,

SP = fraction reporting as manufacturing-downgraded scrap in manganese flow model (37),

and SQ = fraction reporting as processing feed to manufacturing in manganese flow model (37).

Therefore, $SN = 0.40339 \times 0.15679/1.00797$
 $= 0.06275$.

Then $SR = SO \times SS/SQ$, (A-64)

where SR = fraction of 1990 apparent consumption reporting as manufacturing losses,

and SS = fraction reporting as manufacturing losses in manganese flow model (37).

Therefore, $SR = 0.40339 \times 0.01567/1.00797$
 $= 0.00627$.

Then $ST = SO - SN - SR - SU$, (A-65)

where ST = fraction of 1990 apparent consumption reporting as final products,

and SU = fraction reporting as prompt scrap.

Therefore, $ST = 0.40339 - 0.06275 - 0.00627$
 $- 0.04122$
 $= 0.29315$.

Then $SV_n = SW_n \times SM$, (A-66)

where SV_n = amount of manganese in each category,

SW_n = fraction of 1990 apparent consumption of manganese in SHR steels in each category,

and SM = 1990 apparent consumption of manganese in SHR steels.

The results of applying equation A-66 to each category in the manganese flow model for SHR steels are shown in table A-9.

The recycling of scrap results in the loss of about 10 pct of the material (27). The recycled obsolete scrap in 1990 contained 2,400 st of manganese.

Thus, $CT = CU \times 10/90$, (A-67)

where CT = recycling losses of manganese,

CU = manganese in recycled scrap,

10 = percent of recycling losses,

and 90 = percent of materials recovered.

Therefore, $CT = 2,400 \times 10/90$
 $= 267$ st of contained manganese.

Then $CV = CT + CU$, (A-68)

where CV = recovered material for recycling.

$CV = 267 + 2400$

$= 2,667$ st contained manganese in recovered material.

Apparent consumption of manganese in 1985 for SHR steels was 18,694 st of manganese (32).

Applying the factor for final products of SHR steel production (table A-9) to 1985 apparent consumption of manganese gives final products containing 5,481 st of

manganese. Thus, the production loss for 1985 SHR steels is 18,694 (apparent consumption) minus 5,841 (final products), which equals 13,213 st of manganese in production losses in 1985.

Available data estimate that 257,000 st gross weight of SHR steel scrap was exported in 1990 (25). Additional data show the average manganese content of steels to be 0.69 pct (18).

$$\text{Then } CW = CY \times CZ, \quad (\text{A-69})$$

where CW = manganese content of 1990 exported SHR scrap,

CY = amount of SHR steel scrap exported in 1990 (25),

and CZ = average manganese content of steels (18).

$$\text{Therefore, } CW = 257,000 \times 0.0069$$

$$= 1,773 \text{ st of manganese in exported obsolete SHR steel scrap.}$$

$$\text{Then } DA = DB - DC - CV - CW, \quad (\text{A-70})$$

where DA = unknown and unrecovered losses,

DB = 1985 apparent consumption of manganese,

and DC = production losses.

$$\text{Therefore, } DA = 18,694 - 13,213 - 2,667 - 1,773$$

$$= 1,041 \text{ st of manganese in unknown and unrecovered losses.}$$

Table A-10 shows the fractions of 1985 apparent consumption and the amounts of manganese in 1990 recycling of obsolete SHR steel scrap.

FULL ALLOY STEELS

Full alloy steels follow the flow model for all steels for processing operations. The fractions and amounts of manganese for each processing category are shown in table A-11.

However, the fractions for manufacturing losses and downgraded scrap are the same as for chromium in alloy

steels. The fraction for manufacturing-downgraded scrap and manufacturing losses is 0.06303 (37).

Table A-10.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete SHR steel scrap

Category	Fraction ¹	Contained Mn, st
Potentially available for recycling	1.00000	18,694
Production losses	0.70685	13,213
Potential feed to recovery	0.29315	5,480
Exported obsolete scrap	0.09484	1,773
Feed to recovery	0.19831	3,708
Unknown and unrecovered losses	0.05569	1,041
Feed to recycling	0.14267	2,667
Recycling losses	0.01428	267
Recycled obsolete scrap	0.12838	2,400

¹Fraction based on material potentially available for recycling (1985 apparent consumption of Mn in SHR steels) being equal to 1.00000.

Table A-11.—Flow of manganese in full alloy steels in 1990

Category	Fraction	Contained Mn, st
New Mn	0.89594	55,538
Obsolete scrap	0.10406	6,450
1990 apparent consumption	1.00000	61,988
Prompt scrap	0.04122	2,555
Home scrap	0.13476	8,354
Processing losses	0.58755	36,421
Processing-downgraded scrap	0.05028	3,117
Processing feed to manufacturing	0.40339	25,005
Manufacturing-downgraded scrap	0.06303	3,907
Manufacturing losses	0.06303	3,907
Final products	0.23610	14,635

$$\text{Then } DG = DH - DI - DJ - DK, \quad (\text{A-71})$$

where DG = fraction reporting to final products,

DH = fraction reporting to finished steel,

DI = fraction for manufacturing-downgraded scrap,

DJ = fraction for manufacturing losses,

and DK = fraction for prompt scrap.

$$\text{Therefore, } DG = 0.40339 - 0.06303 - 0.06303 - 0.04122$$

$$= 0.23610.$$

Then $DL_n = DM_n \times DN,$ (A-72)

where DL_n = amount of manganese in each category,

DM_n = fraction of 1990 apparent consumption of manganese in full alloy steels in category,

and DN = 1990 apparent consumption of manganese in full alloy steels.

The results of applying equation A-72 to each category in the manganese flow model for full alloy steels are shown in table A-11.

Full alloy steel products are estimated to have a use life of 5 years (5). Thus, obsolete scrap available for consumption in 1990 would come from 1985 apparent consumption of manganese in full alloy steels. Apparent consumption of manganese in 1985 in full alloy steels was estimated to be 51,200 st of contained manganese. Obsolete scrap consumed by full alloy steels in 1990 was estimated to contain 6,450 st of manganese. Literature sources show that about 10 pct of metal recovered is lost during recycling (27).

Then $DO = DP \times 10/90,$ (A-73)

where DO = recycling losses,

DP = manganese recycled to full alloy steels,

10 = percent of recovered material lost in recycling (27),

and 90 = percent of recovered material recycled (27).

Therefore, $DO = 6,450 \times 10/90$

$= 717$ st contained manganese.

Then $DQ = DO + DP,$ (A-74)

where DQ = manganese in recovered material.

Therefore, $DQ = 6,450 + 717$

$= 7,167$ st of manganese recovered.

Assuming that losses and downgraded material were in proportion to those in 1990,

then $DR_n = DS_n \times DT,$ (A-75)

where DR_n = contained manganese in a loss or downgraded material,

DS_n = fraction of apparent consumption in that material,

and DT = 1985 apparent consumption of manganese in full alloy steels.

The results of applying equation A-75 are shown in table A-12.

Table A-12.—Downgraded scrap and loss material in 1985 production of full alloy steels

Category	Fraction	Contained Mn, st
Processing losses	0.58755	30,083
Processing-downgraded scrap	0.05028	2,574
Manufacturing-downgraded scrap	0.06303	3,227
Manufacturing losses	0.06303	3,227
Total production losses		39,111

Now $DU = DV - DW,$ (A-76)

where DU = manganese content of material available for recovery,

DV = manganese apparent consumption in full alloy steels in 1985,

and DW = manganese content of 1985 production losses in full alloy steels.

Therefore, $DU = 51,200 - 39,111$

$= 12,089$ st contained manganese.

Then $DY = DU - DQ,$ (A-77)

where DY = unknown and unrecovered losses.

Therefore, $DY = 12,089 - 7,167$

$= 4,922$ st contained manganese.

Then $DZ_n = EA_n/DV,$ (A-78)

where DZ_n = fraction in a recycling category,

and EA_n = contained manganese in a recycling category.

The results of applying equation A-78 are shown in table A-13.

Table A-13.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete full alloy steel scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling . . .	1.00000	51,200
Production losses	0.76389	39,111
Feed to recovery	0.23611	12,089
Unknown and unrecovered losses . . .	0.09613	4,922
Feed to recycling	0.13998	7,167
Recycling losses	0.01400	717
Recycled obsolete scrap	0.12598	6,450

HIGH-STRENGTH LOW-ALLOY STEELS

HSLA steels follow the flow model for all steels for processing operations. The fractions and amounts of manganese for each processing category are shown in table A-14.

Table A-14.—Flow of manganese in HSLA steels in 1990

Category	Fraction	Contained Mn, st
New Mn	0.89594	35,053
Obsolete scrap	0.10406	4,071
1990 apparent consumption	1.00000	39,124
Prompt scrap	0.04122	1,613
Home scrap	0.13476	5,272
Processing losses	0.58755	22,987
Processing-downgraded scrap	0.05028	1,967
Processing feed to manufacturing . . .	0.40339	15,782
Manufacturing-downgraded scrap . . .	0.06302	2,466
Manufacturing losses	0.06302	2,466
Final products	0.23613	9,238

However, the fractions for manufacturing losses and downgraded scrap are the same as for chromium in HSLA steels. The fraction for manufacturing-downgraded scrap and manufacturing losses is 0.06302 (37).

$$\text{Then } EF = EG - EH - EI - EJ, \quad (\text{A-79})$$

where EF = fraction reporting to final products,

EG = fraction reporting to finished steel,

EH = fraction for manufacturing-downgraded scrap,

EI = fraction for manufacturing losses,

and EJ = fraction for prompt scrap.

$$\begin{aligned} \text{Therefore, } EF &= 0.40339 - 0.06302 - 0.06302 \\ &\quad - 0.04122 \\ &= 0.23613. \end{aligned}$$

$$\text{Then } EK_n = EL_n \times EM, \quad (\text{A-80})$$

where EK_n = amount of manganese in each category,

EL_n = fraction of 1990 apparent consumption of manganese in HSLA steels in category,

and EM = 1990 apparent consumption of manganese in HSLA steels.

The results of applying equation A-80 to each category in the manganese flow model for HSLA steels are shown in table A-14.

HSLA steel products are estimated to have a use life of 5 years (5). Thus, obsolete scrap available for consumption in 1990 would come from 1985 apparent consumption of manganese in HSLA steels. Apparent consumption of manganese in 1985 in HSLA steels was estimated to be 43,291 st of contained manganese. Obsolete scrap consumed by HSLA steels in 1990 was estimated to contain 4,071 st of manganese. Literature sources show that about 10 pct of metal recovered is lost during recycling (27).

$$\text{Then } EN = EO \times 10/90, \quad (\text{A-81})$$

where EN = recycling losses,

EO = manganese recycled to HSLA steels,

10 = percent of recovered material lost in recycling (27),

and 90 = percent of recovered material recycled (27).

$$\text{Therefore, } EN = 4,071 \times 10/90$$

$$= 452 \text{ st contained manganese.}$$

$$\text{Then } EP = EN + EO, \quad (\text{A-82})$$

where EP = manganese in recovered material.

$$\text{Therefore, } EP = 452 + 4,071$$

$$= 4,523 \text{ st of manganese recovered.}$$

Assuming that losses and downgraded material were in proportion to those in 1990,

$$\text{then } EQ_n = ER_n \times ES, \quad (\text{A-83})$$

where EQ_n = contained manganese in a loss or downgraded material,

ER_n = fraction of apparent consumption in that material,

and ES = 1985 apparent consumption of manganese in HSLA steels.

The results of applying equation A-83 are shown in table A-15.

Table A-15.—Downgraded scrap and loss material in 1985 production of HSLA steels

Category	Fraction	Contained Mn, st
Processing losses	0.58755	25,436
Processing-downgraded scrap	0.05028	2,177
Manufacturing-downgraded scrap	0.06302	2,728
Manufacturing losses	0.06302	2,728
Total production losses		33,069

Now $ET = EU - EV$, (A-84)

where ET = manganese content of material available for recovery,

EU = manganese apparent consumption in HSLA steels in 1985,

and EV = manganese content of 1985 production losses in HSLA steels.

Therefore, $ET = 43,291 - 33,069$
 $= 10,222$ st contained manganese.

Then $EW = ET - EP$, (A-85)

where EW = unknown and unrecovered losses.

Therefore, $EW = 10,222 - 4,523$
 $= 5,699$ st contained manganese.

Then $EY_n = EZ_n/EU$, (A-86)

where EY_n = fraction in a recycling category,

and EZ_n = contained manganese in a recycling category.

The results of applying equation A-86 are shown in table A-16.

Table A-16.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete HSLA steel scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	43,291
Production losses	0.76388	33,069
Feed to recovery	0.23612	10,222
Unknown and unrecovered losses	0.13164	5,699
Feed to recycling	0.10448	4,523
Recycling losses	0.01044	452
Recycled obsolete scrap	0.09404	4,071

TOOL STEELS

Tool steels follow the flow model for all steels for processing operations. The fractions and amounts of manganese for each processing category are shown in table A-17.

Table A-17.—Flow of manganese in tool steels in 1990

Category	Fraction	Contained Mn, st
New Mn	0.89594	299
Obsolete scrap	0.10406	35
1990 apparent consumption	1.00000	334
Prompt scrap	0.04122	14
Home scrap	0.13476	45
Processing losses	0.58755	196
Processing-downgraded scrap	0.05028	17
Processing feed to manufacturing	0.40339	135
Manufacturing-downgraded scrap	0.06299	21
Manufacturing losses	0.06299	21
Final products	0.23619	79

However, the fractions for manufacturing losses and downgraded scrap are the same as for chromium in tool steels. The fraction for manufacturing-downgraded scrap and manufacturing losses is 0.06299 (37).

Then $FE = FF - FG - FH - FI$, (A-87)

where FE = fraction reporting to final products,

FF = fraction reporting to finished steel,

FG = fraction for manufacturing-downgraded scrap,

FH = fraction for manufacturing losses,

and FI = fraction for prompt scrap.

Therefore, $FE = 0.40339 - 0.06299 - 0.06299 - 0.04122$
 $= 0.23619.$

Then $FJ_n = FK_n \times FL,$ (A-88)

where FJ_n = amount of manganese in each category,

FK_n = fraction of 1990 apparent consumption of manganese in tool steels in category,

and FL = 1990 apparent consumption of manganese in tool steels.

The results of applying equation A-88 to each category in the manganese flow model for tool steels are shown in table A-17.

Tool steel products are estimated to have a use life of 5 years (5). Thus, obsolete scrap available for consumption in 1990 would come from 1985 apparent consumption of manganese in tool steels. Apparent consumption of manganese in 1985 in tool steels was estimated to be 440 st of contained manganese. Obsolete scrap consumed by tool steels in 1990 was estimated to contain 35 st of manganese. Literature sources show that about 10 pct of metal recovered is lost during recycling (27).

Then $FM = FN \times 10/90,$ (A-89)

where FM = recycling losses,

FN = manganese recycled to tool steels,

10 = percent of recovered material lost in recycling (27),

and 90 = percent of recovered material recycled (27).

Therefore, $FM = 35 \times 10/90$

$= 4$ st contained manganese.

Then $FO = FM + FN,$ (A-90)

where FO = manganese in recovered material.

Therefore, $FO = 4 + 35$

$= 39$ st of manganese recovered.

Assuming that losses and downgraded material were in proportion to those in 1990,

then $FP_n = FQ_n \times FR,$ (A-91)

where FP_n = contained manganese in a loss or downgraded material,

FQ_n = fraction of apparent consumption in that material,

and FR = 1985 apparent consumption of manganese in tool steels.

The results of applying equation A-91 are shown in table A-18.

Table A-18.—Downgraded scrap and loss material in 1985 production of tool steels

Category	Fraction	Contained Mn, st
Processing losses	0.58755	259
Processing-downgraded scrap	0.05028	22
Manufacturing-downgraded scrap	0.06299	28
Manufacturing losses	0.06299	28
Total production losses		336

Now $FS = FT - FU,$ (A-92)

where FS = manganese content of material available for recovery,

FT = manganese apparent consumption in tool steels in 1985,

and FU = manganese content of 1985 production losses in tool steels.

Therefore, $FS = 440 - 336$

$= 104$ st contained manganese.

Then $FV = FS - FO,$ (A-93)

where FV = unknown and unrecovered losses.

Therefore, $FV = 104 - 39$

$= 65$ st contained manganese.

Then $FW_n = FY_n/FI,$ (A-94)

where FW_n = fraction in a recycling category,

and FY_n = contained manganese in a recycling category.

The results of applying equation A-94 are shown in table A-19.

Table A-19.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete tool steel scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling . . .	1.00000	440
Production losses	0.76364	336
Feed to recovery	0.23636	104
Unknown and unrecovered losses . . .	0.14773	65
Feed to recycling	0.08864	39
Recycling losses	0.00909	4
Recycled obsolete scrap	0.07955	35

UNSPECIFIED STEELS

Unspecified steels follow the flow model for all steels for processing operations. The fractions and amounts of manganese for each processing category are shown in table A-20.

Table A-20.—Flow of manganese in unspecified steels in 1990

Category	Fraction	Contained Mn, st
New Mn	0.89594	3,061
Obsolete scrap	0.10406	356
1990 apparent consumption	1.00000	3,417
Prompt scrap	0.04122	141
Home scrap	0.13476	460
Processing losses	0.58755	2,008
Processing-downgraded scrap	0.05028	172
Processing feed to manufacturing . . .	0.40339	1,378
Manufacturing-downgraded scrap . . .	0.06306	215
Manufacturing losses	0.06306	215
Final products	0.23605	807

However, the fractions for manufacturing losses and downgraded scrap are the same as for chromium in alloy steels. The fraction for manufacturing-downgraded scrap and manufacturing losses is 0.06306 (37).

Then $GD = GE - GF - GG - GH$, (A-95)

where GD = fraction reporting to final products,

GE = fraction reporting to finished steel,

GF = fraction for manufacturing-downgraded scrap,

GG = fraction for manufacturing losses,

and GH = fraction for prompt scrap.

Therefore, $GD = 0.40339 - 0.06306 - 0.06306 - 0.04122$

$= 0.23605$.

Then $GI_n = GJ_n \times GK$, (A-96)

where GI_n = amount of manganese in each category,

GJ_n = fraction of 1990 apparent consumption of manganese in unspecified steels in category,

and GK = 1990 apparent consumption of manganese in unspecified steels.

The results of applying equation A-96 to each category in the manganese flow model for unspecified steels are shown in table A-20.

Unspecified steel products are estimated to have a use life of 5 years (5). Thus, obsolete scrap available for consumption in 1990 would come from 1985 apparent consumption of manganese in unspecified steels. Apparent consumption of manganese in 1985 in unspecified steels was estimated to be 1,442 st of contained manganese. Obsolete scrap consumed by unspecified steels in 1990 was estimated to contain 356 st of manganese. Literature sources show that about 10 pct of metal recovered is lost during recycling (27).

Then $GL = GM \times 10/90$, (A-97)

where GL = recycling losses,

GM = manganese recycled to unspecified steels,

10 = percent of recovered material lost in recycling (27),

and 90 = percent of recovered material recycled (27).

Therefore, $GL = 356 \times 10/90$

$= 40$ st contained manganese.

Then $GN = GL + GM$, (A-98)

where GN = manganese in recovered material.

$$\begin{aligned} \text{Therefore, } GN &= 40 + 356 \\ &= 396 \text{ st of manganese recovered.} \end{aligned}$$

Assuming that losses and downgraded material were in proportion to those in 1990,

$$\text{then } GO_n = GP_n \times GQ, \quad (\text{A-99})$$

where GO_n = contained manganese in a loss or downgraded material,

GP_n = fraction of apparent consumption in that material,

and GQ = 1985 apparent consumption of manganese in unspecified steels.

The results of applying equation A-99 are shown in table A-21.

Table A-21.—Downgraded scrap and loss material in 1985 production of unspecified alloy steels

Category	Fraction	Contained Mn, st
Processing losses	0.58755	847
Processing-downgraded scrap	0.05028	73
Manufacturing-downgraded scrap	0.06306	91
Manufacturing losses	0.06306	91
Total production losses		1,102

$$\text{Now } GR = GS - GT, \quad (\text{A-100})$$

where GR = manganese content of material available for recovery,

GS = manganese apparent consumption in unspecified steels in 1985,

and GT = manganese content of 1985 production losses in unspecified steels.

$$\begin{aligned} \text{Therefore, } GR &= 1,442 - 1,102 \\ &= 340 \text{ st contained manganese.} \end{aligned}$$

$$\text{Then } GU = GR - GN, \quad (\text{A-101})$$

where GU = unknown and unrecovered losses.

$$\begin{aligned} \text{Therefore, } GU &= 340 - 396 \\ &= -56 \text{ st contained manganese.} \end{aligned}$$

Because the manganese content of recovered material is greater than the manganese content of material available for recovery, one must assume that another source material of manganese-containing steels other than obsolete scrap from unspecified steels was supplied to the producers as obsolete scrap feed in 1990.

Then, assuming that recovery losses were insignificant, 340 st of contained manganese in obsolete scrap was fed to recycling. Using the same 10-pct loss in recycling as shown above (27),

$$\text{then } GV = GR \times 0.10, \quad (\text{A-102})$$

where GV = recycling losses,

and 0.10 = fraction of recycling feed that reports to recycling losses.

$$\begin{aligned} \text{Therefore, } GV &= 340 \times 0.10 \\ &= 34 \text{ st contained manganese in recycling losses.} \end{aligned}$$

$$\text{Now } GW = GR - GV, \quad (\text{A-103})$$

where GW = contained manganese in recycled unspecified steel obsolete scrap.

$$\begin{aligned} \text{Therefore, } GW &= 340 - 34 \\ &= 306 \text{ st manganese to new production of unspecified steels.} \end{aligned}$$

$$\text{Then } GY = GM - GW, \quad (\text{A-104})$$

where GY = manganese contained in obsolete scrap consumed from other steels that is processed to produce unspecified steels.

$$\begin{aligned} \text{Therefore, } GY &= 356 - 306 \\ &= 50 \text{ st contained manganese in other than unspecified steels consumed in unspecified steel production.} \end{aligned}$$

$$\text{Then } GZ_n = HA_n / GS, \quad (\text{A-105})$$

where GZ_n = fraction in a recycling category,

and HA_n = contained manganese in a recycling category.

The results of applying equation A-105 are shown in table A-22.

Table A-22.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete unspecified steel scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	1,442
Production losses	0.76422	1,102
Feed to recovery	0.23578	340
Unknown and unrecovered losses	0.00000	0
Feed to recycling	0.23578	340
Recycling losses	0.02358	34
Recycled obsolete scrap from unspecified steels	0.21221	306
Recycled obsolete scrap from other steels	0.03467	50

CAST IRONS

Desy (24) states that charges for cast irons contain 94 pct scrap and 6 pct new metal. Schottman (37) states that in 1993 scrap consumption in cast irons was 61.8 million st, of which 27.2 million st was home scrap and the remainder of 34.6 million was purchased scrap. The purchased scrap breaks down to 20.8 million st (60 pct) obsolete scrap and 13.8 million st (40 pct) prompt scrap (38). The fractions of each type of scrap are then

$$HB_n = HC \times HD_n / HE, \quad (A-106)$$

where HB_n = fraction of the consumed scrap, for the category,

HC = total fraction of scrap consumed (0.94),

HD_n = amount of scrap category consumed,

and HE = total amount of scrap consumed.

The results of equation A-106 are shown in table A-23.

Apparent consumption in 1990 is assumed to equal 1.00000 and contains new metal and obsolete scrap (0.06000 + 0.31577 = 0.37577).

$$\text{Then } HF_n = HB_n / HG, \quad (A-107)$$

where HF_n = fraction of 1990 apparent consumption in each category,

and HG = sum of fractions of new metal and obsolete scrap (1990 apparent consumption in cast iron).

The results of equation A-107 are also shown in table A-23.

Table A-23.—Furnace charge material in 1990 production of cast irons

Category	Scrap consumed, million st	Fraction of furnace charge	Fraction of 1990 apparent consumption	Mn content, st
Home scrap	27.2	0.41372	1.10099	17,645
Obsolete scrap	20.76	0.31577	0.84033	13,467
Prompt scrap	13.84	0.21051	0.56021	8,978
New metal	NAp	0.06000	0.15967	2,559
Total	61.80	1.00000	2.66120	42,648

NAp Not applicable.

In 1990, cast iron industries consumed 16,026 st of manganese (1).

$$\text{Then } HH_n = HF_n \times HJ, \quad (A-108)$$

where HH_n = manganese consumed in each category in 1990,

and HJ = 1990 apparent consumption of manganese in cast irons (1).

The results of equation A-108 are also shown in table A-23.

Johns shows that in iron processing, for every 14.76 st of manganese added, 3.69 st of manganese reports to processing losses in slag, dust, etc. (18).

$$\text{Then } HK = HL \times HM, \quad (A-109)$$

where HK = fraction of manganese in processing losses,

HL = fraction of total furnace charge,

and HM = ratio of manganese in processing losses to total furnace charge of manganese.

$$\text{Therefore, } HK = 2.66120 \times 3.69 / 14.76$$

$$= 0.66530.$$

$$\text{Then } HN = HK \times HJ, \quad (A-110)$$

where HN = manganese in processing losses.

Therefore, $HN = 0.66530 \times 16,026$
 $= 10,662$ st of manganese reporting to processing losses.

Now $HO = HP - HQ - HN,$ (A-111)

where $HO =$ processing feed to manufacturing,
 $HP =$ total processing charge of manganese,
 and $HQ =$ home scrap.

Therefore, $HO = 42,648 - 17,645 - 10,662$
 $= 14,341$ st of manganese in processing feed to manufacturing.

Manufacturing losses are assumed to be the same fraction of processing feed to manufacturing as in chromium in cast irons (37).

Then $HR = HO \times 0.01771/1.13201,$ (A-112)

where $HR =$ manganese in manufacturing losses,
 $0.01771 =$ fraction of manufacturing losses for chromium (manganese) in cast irons,
 and $1.13201 =$ fraction of processing feed to manufacturing for chromium (manganese) in cast irons.

Therefore, $HR = 14,341 \times 0.01771/1.13201$
 $= 224$ st of manganese in manufacturing losses.

Now $HS = HO - HR - HT,$ (A-113)

where $HS =$ manganese in final cast iron products,
 and $HT =$ manganese in prompt scrap.

Therefore, $HS = 14,341 - 224 - 8,978$
 $= 5,139$ st manganese in cast iron final products.

Now $HU_n = HV_n/HJ,$ (A-114)

where $HU_n =$ fraction of apparent consumption in each category, for cast irons in 1990,

and $HV_n =$ manganese in each category.

The results of equation A-114 are shown in table A-24.

Table A-24.—Fraction of 1990 apparent consumption and contained short tons of manganese in each category for cast irons

Category	Fraction	Contained Mn, st
New Mn	0.15967	2,559
Obsolete scrap	0.84033	13,467
Prompt scrap	0.56021	8,978
Home scrap	1.10099	17,645
Processing losses	0.66530	10,662
Processing feed to manufacturing	0.89486	14,341
Manufacturing losses	0.01398	224
Final products	0.32067	5,139

Because cast irons have a 10-year life cycle, obsolete scrap would come from 1980 apparent consumption of manganese (18). Apparent consumption of manganese in 1980 in cast irons was 26,492 st of contained manganese (34). Assuming that fractions of processing losses and manufacturing losses were the same as derived for 1990 consumption,

then $HY_n = HZ \times IA_n,$ (A-115)

where $HY_n =$ manganese in each category for cast irons,
 $HZ =$ 1980 apparent consumption of manganese in cast irons,

and $IA_n =$ fraction of apparent consumption that reports to each category for cast irons in 1980.

Applying equation A-115 to the 1980 apparent consumption of manganese in cast irons gives values of 17,625 st of manganese in processing losses and 370 st of manganese in manufacturing losses.

Then $IB = HZ - ID - IE,$ (A-116)

where $IB =$ manganese in obsolete scrap available for recovery,
 $IC =$ manganese in 1980 reporting to processing losses,

and $ID =$ manganese in 1980 reporting to manufacturing losses.

Therefore, $IB = 26,492 - 17,625 - 370$
 $= 8,497$ st of manganese in obsolete scrap cast iron materials available for recovery in 1990.

Assuming that no manganese in cast irons is lost during recovery, then 8,497 st of contained manganese is available for recycling in 1990. About 10 pct of material sent to recycling is lost as waste (27).

Then $IE = IB \times 0.10,$ (A-117)

where $IE =$ recycling losses,

and $0.10 =$ fraction of feed to recycling that reports to recycling losses (27).

Therefore, $IE = 8,497 \times 0.10$
 $= 850$ st manganese in recycling losses.

Then $IF = IB - IE,$ (A-118)

where $IF =$ manganese in recycled cast irons.

Therefore, $IF = 8,497 - 850$
 $= 7,647$ st of manganese in recycled obsolete scrap cast irons.

Previous calculations and estimates showed that 1990 consumption of manganese in obsolete scrap equaled 13,467 st contained manganese. The remainder above 7,647 st of manganese would then come from other ferrous scrap steels.

Then $IG = 13,467 - IF,$ (A-119)

where $IG =$ manganese-containing recycled material from other ferrous (steel) scrap (probably mostly downgraded material).

Therefore, $IG = 13,467 - 7,647$
 $= 5,820$ st contained manganese in other recycled obsolete scrap.

Then $IH_n = IJ_n / HZ,$ (A-120)

where $IH_n =$ fraction in a recycling category,

$IJ_n =$ contained manganese in a recycling category,

and $HZ =$ 1980 apparent consumption of manganese in cast irons.

The results of applying equation A-120 are shown in table A-25.

Table A-25.—Fraction of 1980 apparent consumption and amount of manganese in 1990 recycling of obsolete cast iron scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	26,492
Production losses	0.67926	17,995
Feed to recovery	0.32074	8,497
Unknown and unrecovered losses	0.00000	0
Feed to recycling	0.32074	8,497
Recycling losses	0.03207	850
Recycled obsolete scrap from cast irons	0.28866	7,647
Recycled obsolete scrap from other steels	0.21968	5,820
Total obsolete scrap	0.50834	13,467

SUPERALLOYS

Because most superalloys are vacuum-melted metals, the losses of manganese are assumed to follow the same patterns as losses of chromium in this industry.

Then $IK_n = IL \times IM_n,$ (A-121)

where $IK_n =$ amount of manganese in each category,

$IL =$ 1990 apparent consumption of manganese in superalloys,

and $IM_n =$ fraction of chromium (or manganese) in each category (37).

The results of applying equation A-121 to the 1990 apparent consumption of manganese in superalloys are shown in table A-26.

Table A-26.—Fraction and amount of manganese in flow model for superalloys in 1990

Category	Fraction	Contained Mn, st
New Mn	0.82671	198
Obsolete scrap	0.17329	41
1990 apparent consumption	1.00000	239
Prompt scrap	0.33907	81
Home scrap	0.93772	224
Processing losses	0.01804	4
Processing-downgraded material	0.03077	7
Processing feed to manufacturing	1.29034	308
Manufacturing-downgraded material	0.13697	33
Manufacturing losses	0.10709	26
Prompt scrap to export	0.12497	30
Final products	0.58216	139

Superalloys have a 5-year use life (5). Thus, the obsolete scrap available for recycling would have come from 1985 production. Apparent consumption of manganese in superalloys in 1985 was 414 st contained manganese (32). Calculations above have estimated that obsolete scrap recycling to 1990 apparent consumption was 41 st of contained manganese. About 10 pct of feed to recycling is lost in the recycling process (27).

Then $IN = IO \times 10/90,$ (A-122)

where IN = recycling losses of manganese,
 IO = amount of manganese recycled to 1990 superalloy production,

10 = percent in recycling losses (27),

and 90 = percent of material recycled.

Therefore, $IN = 41 \times 10/90$
 $= 5$ st of manganese in recycling losses.

Then $IR = IO + IN,$ (A-123)

where IR = recovered material feed to recycling.

Therefore, $IR = 41 + 5$
 $= 46$ st manganese in recovered material for feed to recycling.

Production losses, exports, and downgraded materials for superalloys in 1985 were assumed to be in the same ratio as in the 1990 superalloy flow model.

Then $IS_n = IT \times IU_n,$ (A-124)

where IS_n = quantity of manganese in each category,

IT = 1985 apparent consumption of manganese in superalloys,

and IU_n = fraction of 1985 apparent consumption in each category.

The results of applying equation A-124 are shown in table A-27.

Table A-27.—Fraction and amount of contained manganese in each production category in 1985

Category	Fraction	Contained Mn, st
Processing losses	0.01804	7
Processing-downgraded scrap	0.03077	13
Manufacturing-downgraded scrap	0.10709	44
Manufacturing losses	0.13697	57
Prompt scrap to export	0.12497	52
Total production losses	0.41784	173

Then $IV = IT - IW,$ (A-125)

where IV = contained manganese in feed to recovery,

and IW = sum of production losses.

Therefore, $IV = 414 - 173$
 $= 241$ st manganese in feed to recovery.

Then $IY = IV - IR,$ (A-126)

where IY = unknown and unrecovered losses.

Therefore, $IY = 241 - 46$
 $= 195$ st manganese in unknown and unrecovered losses.

Now $IZ_n = JA_n/IT,$ (A-127)

where IZ_n = fraction of manganese in each category based on 1985 apparent consumption being equal to 1.00000,

and JA_n = contained manganese in each category.

Applying equation A-127 to the data gives the fraction in each recycling category as shown in table A-28.

Table A-28.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete superalloy scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	414
Production losses	0.41787	173
Feed to recovery	0.58213	241
Unknown and unrecovered losses	0.47101	195
Feed to recycling	0.11111	46
Recycling losses	0.01100	5
Recycled obsolete scrap	0.09903	41

OTHER ALLOYS

Manganese in this class of alloys is treated using the same flow model as chromium flow in this class of alloys (37). Recycling of other alloys, especially aluminum alloys used in beverage containers, is carried out. The data available (for 1985) show that about 47 pct of beverage containers are recycled (39). (Note: These data were the latest data available in late 1992). Other copper alloys such as manganese bronze are also recycled, but the life spans of these products are much longer.

Aluminum-manganese alloys used in beverage containers are assumed to be the major end use in "other alloys." Assuming that this end use is 70 pct of other alloy consumption of manganese, then 0.7×47 or about 32.9 pct of manganese consumption in other alloys is from recycled obsolete scrap. With 32.9 pct of manganese in other alloys as recycled obsolete scrap,

$$\text{then } \quad \text{JB} = \text{JC} - \text{JD}, \quad (\text{A-128})$$

where JB = fraction of manganese in new material,

JC = total consumption (1.00000),

and JD = fraction recycled manganese in obsolete scrap.

$$\begin{aligned} \text{Therefore, } \text{JB} &= 1.00000 - 0.32900 \\ &= 0.67100. \end{aligned}$$

$$\text{Now } \quad \text{JE}_n = \text{JF} \times \text{JG}_n, \quad (\text{A-129})$$

where JE_n = manganese in each production category,

JF = 1990 apparent consumption of manganese in other alloys,

and JG_n = fraction of manganese in each category (37).

The application of equation A-129 to the 1990 apparent consumption of manganese in other alloys is given in the upper portion of table A-29.

Table A-29.—Fraction and amount of manganese in each category of flow model for other alloys in 1990

Category	Fraction	Contained Mn, st
New Mn	0.67100	17,638
Obsolete scrap	0.32900	8,648
1990 apparent consumption	1.00000	26,286
Prompt scrap	0.16663	4,380
Home scrap	0.20268	5,328
Processing losses	0.17125	4,501
Processing feed to manufacturing	0.99562	26,171
Manufacturing losses	0.01559	410
Final products	0.81340	21,381

Beverage cans generally are recycled within 3 to 4 months of their production. Because beverage cans are the majority end use in "other alloys," the obsolete scrap would be recycled in the same year as the cans are produced; thus, "other alloys" obsolete scrap would come from 1990 production. Approximately 10 pct of feed to recycling reports as recycling losses (27).

$$\text{Then } \quad \text{JH} = \text{JI} \times 10/90, \quad (\text{A-130})$$

where JH = recycling losses,

JI = manganese recycled in 1990 as obsolete scrap of other alloys,

10 = percent of recycling losses (27),

and 90 = percent of material recycled.

$$\begin{aligned} \text{Therefore, } \text{JH} &= 8,648 \times 10/90 \\ &= 961 \text{ st of manganese in recycling losses.} \end{aligned}$$

$$\text{Then } \quad \text{JL} = \text{JI} + \text{JH}, \quad (\text{A-131})$$

where JL = feed to recycling.

$$\begin{aligned} \text{Therefore, } \text{JL} &= 8,648 + 961 \\ &= 9,609 \text{ st manganese in recycling feed.} \end{aligned}$$

Then $JM_n = JN \times JO_n$, (A-132)

where JM_n = production loss in category,

JN = 1990 apparent consumption of manganese in other alloys,

and JO_n = fraction of 1990 apparent consumption of manganese in other alloys in each production loss category.

The results show that processing losses equalled 4,501 st of manganese, and manufacturing losses equalled 410 st of manganese, for a total of 4,911 st manganese in production losses.

Then $JP = JN - JQ$, (A-133)

where JP = manganese in obsolete scrap available for recovery,

and JQ = manganese in production losses in other alloys in 1990.

Therefore, $JP = 26,286 - 4,911$
 $= 21,375$ st contained manganese in obsolete scrap available for recovery.

Then $JR = JP - JL$, (A-134)

where JR = unknown and unrecovered losses of manganese in recovery of obsolete scrap from other alloys.

Therefore, $JR = 21,375 - 9,609$
 $= 11,766$ st of manganese in feed to recycling.

Now $JS_n = JT_n/JN$, (A-135)

where JS_n = fraction of material potentially available for recycling (1990 apparent consumption of manganese in other alloys) in each recycling category,

and JT_n = manganese in each recycling category.

The results of applying equation A-135 are shown in table A-30.

Table A-30.—Fraction of 1990 apparent consumption and amount of manganese in 1990 recycling of obsolete other alloys scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	26,286
Production losses	0.18683	4,911
Feed to recovery	0.81317	21,375
Unknown and unrecovered losses	0.44762	11,766
Feed to recycling	0.36555	9,609
Recycling losses	0.03656	961
Recycled obsolete scrap	0.32900	8,648

MISCELLANEOUS AND UNSPECIFIED MATERIALS

This material contains miscellaneous and unspecified end uses of manganese. This category also includes withheld data on consumption of high-carbon ferromanganese in superalloys and on consumption of medium- and low-carbon ferromanganese and silicomanganese in other alloys. Thus, there is some recycling of material in this category. Superalloys have about a 17-pct recycle of obsolete material in their consumption of manganese, and other alloys have a 32.9-pct recycle of obsolete material in their consumption of manganese. For development of the flow model for miscellaneous and unspecified materials, the average recycle value, $(17 + 32.9)/2 = 24.95$ pct, is assumed to be the percent recycle of miscellaneous and unspecified materials.

Then $JU = 1.00000 - 0.2495$, (A-136)

where JU = fraction of new material consumed in miscellaneous and unspecified materials,

1.00 = the entire fraction of manganese consumed in miscellaneous and unspecified materials (1990 apparent consumption in this end use),

and 0.2495 = recycled obsolete scrap consumed expressed as a fraction.

Therefore, $JU = 1.00000 - 0.2495$
 $= 0.7505$.

All other categories of material are assumed the same as for chromium in miscellaneous and unspecified materials (37). Apparent consumption of manganese in miscellaneous and unspecified material in 1990 was 9,654 st contained manganese.

Now $JV_n = JW \times JY_n$, (A-137)

where JV_n = quantity of consumed manganese in category in flow model for miscellaneous and unspecified materials,

JW = 1990 apparent consumption of manganese in miscellaneous and unspecified materials,

and JY_n = fraction of 1990 apparent consumption of manganese in miscellaneous and unspecified materials in each category of the flow model.

Applying equation A-137 to the data on the flow model for manganese (chromium) in miscellaneous and unspecified materials results in the data in table A-31.

Table A-31.—Fraction of consumption and contained manganese in each flow model category for miscellaneous and unspecified materials for 1990

Category	Fraction	Contained Mn, st
New Mn	0.75050	7,245
Obsolete scrap	0.24950	2,409
1990 apparent consumption	1.00000	9,654
Prompt scrap	0.16694	1,612
Home scrap	0.20295	1,959
Processing losses	0.17185	1,659
Processing-downgraded material	0.04910	474
Processing feed to manufacturing	0.94599	9,133
Manufacturing-downgraded material	0.14894	1,438
Manufacturing losses	0.01473	142
Final products	0.61538	5,941

Obsolete scrap for recycling in 1990 based on a 5-year use life for miscellaneous and unspecified materials would come from 1985 apparent consumption in this end use (32). Consumption in 1985 equaled 12,210 st of contained manganese. Data estimated above indicate that 2,409 st of contained manganese was recycled as obsolete scrap in 1990.

Then $JZ = KA \times 10/90$, (A-138)

where JZ = recycling losses,

KA = manganese recycled in 1990 as miscellaneous and unspecified materials,

10 = percent of recycling losses (27),

and 90 = percent of material recycled.

Therefore, $JZ = 2,409 \times 10/90$

= 268 st of manganese in recycling losses.

Then $KD = KA + JZ$, (A-139)

where KD = feed to recycling.

Therefore, $KD = 2,409 + 268$

= 2,677 st of manganese in feed to recycling.

Then $KE_n = KF \times KG_n$, (A-140)

where KE_n = production loss in category,

KF = 1985 apparent consumption of manganese in miscellaneous and unspecified materials,

and KG_n = fraction of 1985 apparent consumption of manganese in miscellaneous and unspecified materials in each production category.

The results from equation A-140 show the following production losses:

Processing losses = 2,098 st manganese,

Processing-downgraded scrap = 600 st manganese,

Manufacturing-downgraded scrap = 1,819 st manganese, and,

Manufacturing losses = 180 st contained manganese,

for a total production loss of 4,696 st of contained manganese.

Then $KH = KF - KI$, (A-141)

where KH = manganese in obsolete scrap available for recovery,

and KI = manganese in production losses in miscellaneous and unspecified materials in 1985.

Therefore, $KH = 12,210 - 4,696$

= 7,514 st manganese in obsolete scrap available for recovery.

Then $KJ = KH - KD,$ (A-142)

where $KJ =$ unknown and unrecovered losses of manganese in recovering obsolete scrap from miscellaneous and unspecified materials.

Therefore, $KJ = 7,514 - 2,677$
 $= 4,837$ st contained manganese in unknown and unrecovered losses.

Now $KK_n = KL_n/KF,$ (A-143)

where $KK_n =$ fraction of material potentially available for recycling (1985 apparent consumption of manganese in miscellaneous and unspecified materials) in each category,

and $KL_n =$ manganese in each recycling category.

The results of applying equation A-143 are shown in table A-32.

Table A-32.—Fraction of 1985 apparent consumption and amount of manganese in 1990 recycling of obsolete miscellaneous and unspecified material scrap

Category	Fraction	Contained Mn, st
Potentially available for recycling	1.00000	12,210
Production losses	0.38460	4,696
Feed to recovery	0.61540	7,514
Unknown and unrecovered losses	0.39618	4,837
Feed to recycling	0.21922	2,677
Recycling losses	0.02192	268
Recycled obsolete scrap	0.19730	2,409

CHEMICALS

NMAB (5) states that chemical processing is completed with yields of about 97 pct, and in subsequent processing, (manufacturing) yields are lower—about 95 pct. Thus, processing losses are about 3 pct of processing feed, and manufacturing losses are about 5 pct of manufacturing feed. There is essentially no scrap recycling in the manganese chemical industry. Most end uses are dissipative in nature.

Then $KM = KN \times 0.03,$ (A-144)

where $KM =$ fraction of material that is processing losses,

$KN =$ processing feed material (1.0) (1990 chemical apparent consumption),

and $0.03 =$ fraction of processing feed that reports to processing losses.

Therefore, $KM = 1 \times 0.03$
 $= 0.03.$

Then $KO = KN - KM,$ (A-145)

where $KO =$ fraction of processing feed that reports to manufacturing.

Therefore, $KO = 1.00 - 0.03$
 $= 0.97.$

Then $KP = KO \times 0.05,$ (A-146)

where $KP =$ relative fraction of processing feed to manufacturing that reports as manufacturing losses,

and $0.05 =$ fraction of manufacturing feed that reports to manufacturing losses.

Therefore, $KP = 0.97 \times 0.05$
 $= 0.0485.$

Then $KQ = KO - KP,$ (A-147)

where $KQ =$ relative fraction of manufacturing feed that reports as final products.

Therefore, $KQ = 0.97 - 0.0485$
 $= 0.9215.$

Then $KR_n = KS \times KT_n,$ (A-148)

where $KR_n =$ manganese in each category,

$KS =$ 1990 apparent consumption of manganese in the chemical industry,

and $KT_n =$ fraction of 1990 apparent consumption of manganese in the chemical industry that reports in each category.

The results of applying equation A-148 give the values shown in table A-33.

Table A-33.—Fraction of consumption and amount of manganese reporting to each category in manganese chemical industry flow model for 1990

Category	Fraction	Contained Mn, st
New Mn	1.00000	40,000
Processing losses	0.03000	1,200
Processing feed to manufacturing	0.97000	38,800
Manufacturing losses	0.04850	1,940
Final products	0.92150	36,860

BATTERIES

The use of manganese in this industry is a chemical process. Thus, the flow model for batteries will follow the same flow model as that for the chemicals industry, above.

$$\text{Then } KU_n = KV \times KW_n, \quad (\text{A-149})$$

where KU_n = manganese in that category,

KV = 1990 apparent consumption of manganese in the battery industry,

and KW_n = fraction of 1990 apparent consumption of manganese in the battery industry that reports to that category.

The results of applying equation A-149 to consumption data give the values shown in table A-34.

Table A-34.—Fraction of consumption and amount of manganese reporting to each category in manganese battery industry flow model for 1990

Category	Fraction	Contained Mn, st
New Mn	1.00000	46,000
Processing losses	0.03000	1,380
Processing feed to manufacturing	0.97000	44,620
Manufacturing losses	0.04850	2,231
Final products	0.92150	42,389

OVERALL MANGANESE INDUSTRY

This flow model was developed by summing the various categories from each industry's flow model. The data for the overall flow model are shown in table A-35. Table A-36 summarizes the factors for each manganese industry.

Table A-35.—Fraction of 1990 apparent consumption and manganese content of each category for the overall manganese industries

Category	Fraction	Contained Mn, st
1990 flow:		
New Mn	0.88114	606,413
Recycled obsolete scrap	0.11886	81,799
Apparent consumption	1.00000	¹ 688,212
Prompt scrap	0.05481	37,722
Home scrap	0.14425	99,274
Processing losses	0.49776	342,562
Processing-downgraded material	0.04088	28,135
Processing feed to manufacturing	0.51618	355,240
Manufacturing-downgraded material	0.05252	36,144
Manufacturing losses	0.05572	38,244
Final products	0.35309	243,001
Scrap recycling:		
Potential obsolete scrap available ²	1.00000	953,903
Production losses ³	0.67772	646,481
Obsolete scrap exported	0.00186	1,773
Feed to recovery	0.32042	305,649
Unknown and unrecovered losses	0.23198	221,282
Feed to recycling	0.08844	84,367
Recycling losses	0.00885	8,438
Recycled obsolete scrap	0.07960	75,929
Other Mn-bearing scrap ⁴	0.00615	5,870
Total recycled obsolete scrap	0.08575	81,799

¹This figure does not account for losses during domestic ferro-alloy production.

²Apparent consumption in year of production.

³Losses in year of production.

⁴Mn-bearing scrap of unknown origin or end use.

Table A-36.—Factors for consumption and recycling categories for all manganese industries

Category	Carbon steel	SHR steel	Full alloy steel	HSLA steel	Tool steel	Unspecified steel	Cast irons	Super-alloys	Other alloys	Misc. and unspecified	Chemicals	Batteries	Mn industry
New Mn	0.89594	0.89594	0.89594	0.89594	0.89594	0.89594	0.15967	0.82671	0.67100	0.75050	1.00000	1.00000	0.88114
Obsolete scrap	0.10406	0.10406	0.10406	0.10406	0.10406	0.10406	0.84033	0.17329	0.32900	0.24950	NAP	NAP	0.11886
Apparent consumption	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Prompt scrap	0.04122	0.04122	0.04122	0.04122	0.04122	0.04122	0.56021	0.33907	0.16663	0.16694	NAP	NAP	0.05481
Home scrap	0.13476	0.13476	0.13476	0.13476	0.13476	0.13476	1.10099	0.93772	0.20268	0.20295	NAP	NAP	0.14425
Processing losses	0.58755	0.58755	0.58755	0.58755	0.58755	0.58755	0.66530	0.01804	0.17125	0.17185	0.03000	0.03000	0.49776
Processing-downgraded material	0.05028	0.05028	0.05028	0.05028	0.05028	0.05028	NAP	0.03077	NAP	0.04910	NAP	NAP	0.04088
Processing feed to manufacturing	0.40339	0.40339	0.40339	0.40339	0.40339	0.40339	0.89486	1.29034	0.99562	0.94599	0.97000	0.97000	0.51618
Manufacturing-downgraded material	0.06306	0.06275	0.06306	0.06302	0.06299	0.06306	NAP	0.13697	NAP	0.14894	NAP	NAP	0.05252
Manufacturing losses	0.06306	0.00627	0.06306	0.06302	0.06299	0.06306	0.01398	0.10709	0.01559	0.01473	0.04850	0.04850	0.05572
Total downgraded material	0.11334	0.11303	0.11334	0.11334	0.11327	0.11334	NAP	0.16774	NAP	0.19804	NAP	NAP	0.09340
Prompt scrap exported	NAP	NAP	NAP	NAP	NAP	NAP	NAP	0.12497	NAP	NAP	NAP	NAP	0.00004
Final products	0.23605	0.29315	0.23610	0.23613	0.23619	0.23605	0.32067	0.58216	0.81340	0.61538	0.92150	0.92150	0.35309
Potentially available for recycling	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	NAP	NAP	1.00000
Production losses	0.76389	0.70685	0.76389	0.76388	0.76384	0.76422	0.67926	0.41787	0.18683	0.38460	NAP	NAP	0.67772
Obsolete scrap exported	NAP	0.09484	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	0.00186
Obsolete scrap available for recovery	0.23611	0.19831	0.23611	0.23612	0.23636	0.23578	0.32074	0.58213	0.81317	0.61540	NAP	NAP	0.32042
Unknown and unrecovered losses	0.16512	0.05569	0.09613	0.13164	0.14773	NAP	NAP	0.47101	0.44762	0.39618	NAP	NAP	0.23198
Feed to recycling	0.07059	0.14267	0.13998	0.10448	0.08864	0.23578	0.32074	0.11111	0.36555	0.21922	NAP	NAP	0.08844
Recycling losses	0.00710	0.01428	0.01400	0.01044	0.00909	0.02358	0.03207	0.01100	0.03656	0.02192	NAP	NAP	0.00885
Recycled obsolete scrap	0.06389	0.12836	0.12598	0.09404	0.07955	0.21221	0.28866	0.09903	0.32900	0.19730	NAP	NAP	0.07960
Recycled obsolete scrap from other materials	NAP	NAP	NAP	NAP	NAP	0.03467	0.21968	NAP	NAP	NAP	NAP	NAP	0.00615
Total recycled scrap	0.06389	0.12836	0.12598	0.09404	0.07955	0.24688	0.50834	0.09903	0.32900	0.19730	NAP	NAP	0.08575

NAP Not applicable.