U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Manganese Recycling in the United States in 1998

by

Thomas S. Jones

Open File Report 01-304

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

CONTENTS

FIGURES

TABLE

Manganese Recycling in the United States in 1998

By Thomas S. Jones

ABSTRACT

This report describes the flow and processing of manganese within the U.S. economy in 1998 with emphasis on the extent to which manganese is recycled. Manganese was used mostly as an alloying agent in alloys in which it was a minor component. Manganese was recycled mostly within scrap of iron and steel. A small amount was recycled within aluminum used beverage cans. Very little manganese was recycled from materials being recovered specifically for their manganese content. For the United States in 1998, 218,000 metric tons of manganese was estimated to have been recycled from old scrap, of which 96% was from iron and steel scrap. Efficiency of recycling was estimated as 53% and recycling rate as 37%. Metallurgical loss of manganese was estimated to be about 1.7 times that recycled. This loss was mostly into slags from iron and steel production, from which recovery of manganese has yet to be shown economically feasible.

INTRODUCTION

The purpose of this study is to document the extent to which manganese is being recycled in the United States, to identify trends in domestic manganese recycling, and to determine the implications of these trends for sustainability of manganese use. The base year for the study is 1998.

Manganese (atomic number 25) is in Group 7 of the Periodic Table. In that table, its closest neighbors are, to the left, vanadium and chromium and, to the right, iron, cobalt, and nickel. Thus, it is not surprising that manganese should be considered a ferrous metal and that its major use is in iron-base alloys (steel and cast iron). Because manganese metal typically is brittle and unworkable, only a small amount can be used as an alloy in which manganese is the major component. Rather, manganese is used predominantly in alloys where it is a minor component, principally in steel and, to a lesser extent, aluminum. Manganese is essential to steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties.

In nonmetallurgical uses, the most common valences for manganese are two and four, and oxygen is the main element with which manganese is combined. Accordingly, the mineral and commodity chemistry of manganese centers on such compounds as manganous oxide (MnO), manganese dioxide (MnO_2), manganese carbonate ($MnCO_3$), and manganese sulfate ($MnSO_4$). Pyrolusite (a mineral form of manganese dioxide), braunite (an oxysilicate), and rhodochrosite (a manganese carbonate) are among the minerals more commonly found in manganese ores. In 1998, the leading producers of ore were Australia, Brazil, China, Gabon (the leading U.S. source), India, South Africa, and Ukraine.

When a reductant (carbon) is present in the charge to a process for making iron or steel, some manganese ore is used directly. Examples include addition to the charge to an iron blast furnace and direct smelting of ore during steelmaking (Japan). For the most part, however, ore is smelted and reduced to its metallic content by carbon predominantly in submerged-arc electric furnaces but also in blast furnaces. Manganese ores typically contain iron as well so the result of smelting is an iron-bearing ferroalloy, which is used subsequently to add manganese to liquid metal during steelmaking. The principal manganese ferroalloys and their typical components are high-carbon ferromanganese (78% manganese, 7% carbon, balance mostly iron) and silicomanganese (66% manganese, 17% silicon, 2% carbon). An electrolytic process is used to obtain electrolytic manganese dioxide (EMD) and most manganese metal, the two other forms in which manganese is commercially most used. The sequence of steps usually used in producing these two materials is similar—leaching manganese feed with sulfuric acid and electrodepositing EMD or metal from the leach liquor after it has been purified.

Metallurgical applications account for most domestic manganese consumption, of which 85% to 90% has been going to steelmaking and about 8% to the manufacture of dry cell batteries. The preponderance of the manganese used domestically for making batteries is now EMD because usage of natural battery ore has declined greatly. The manufacture of manganese chemicals, such as potassium permanganate, and agricultural use of manganese in animal feed and plant fertilizer as oxide, sulfate, and oxysulfate together account for another 5% of use. These patterns of domestic use are typical for other industrialized countries having well-developed steel industries.

For 1998, the average price for U.S. delivery of metallurgical-grade ore was assessed at $2.40 per metric ton unit, on the basis of cost, insurance, and freight (c.i.f.); and the year-average free-on-board (f.o.b.) price for imported high-carbon ferromanganese was $502 per long ton of alloy (Jones, 2000, p. 49.2-49.3). At per kilogram of contained manganese, these prices equate to 24 cents for ore and 63 cents for high-carbon ferromanganese. For 1993 through 1998, the ore prices were reasonably steady following a decline from a peak of $3.78 per metric ton unit in 1990 (Jones, 1999). In the 1990's through 1998, the price trend for high-carbon ferromanganese has been gradually declining from a maximum of about $650 per long ton of alloy in 1990.

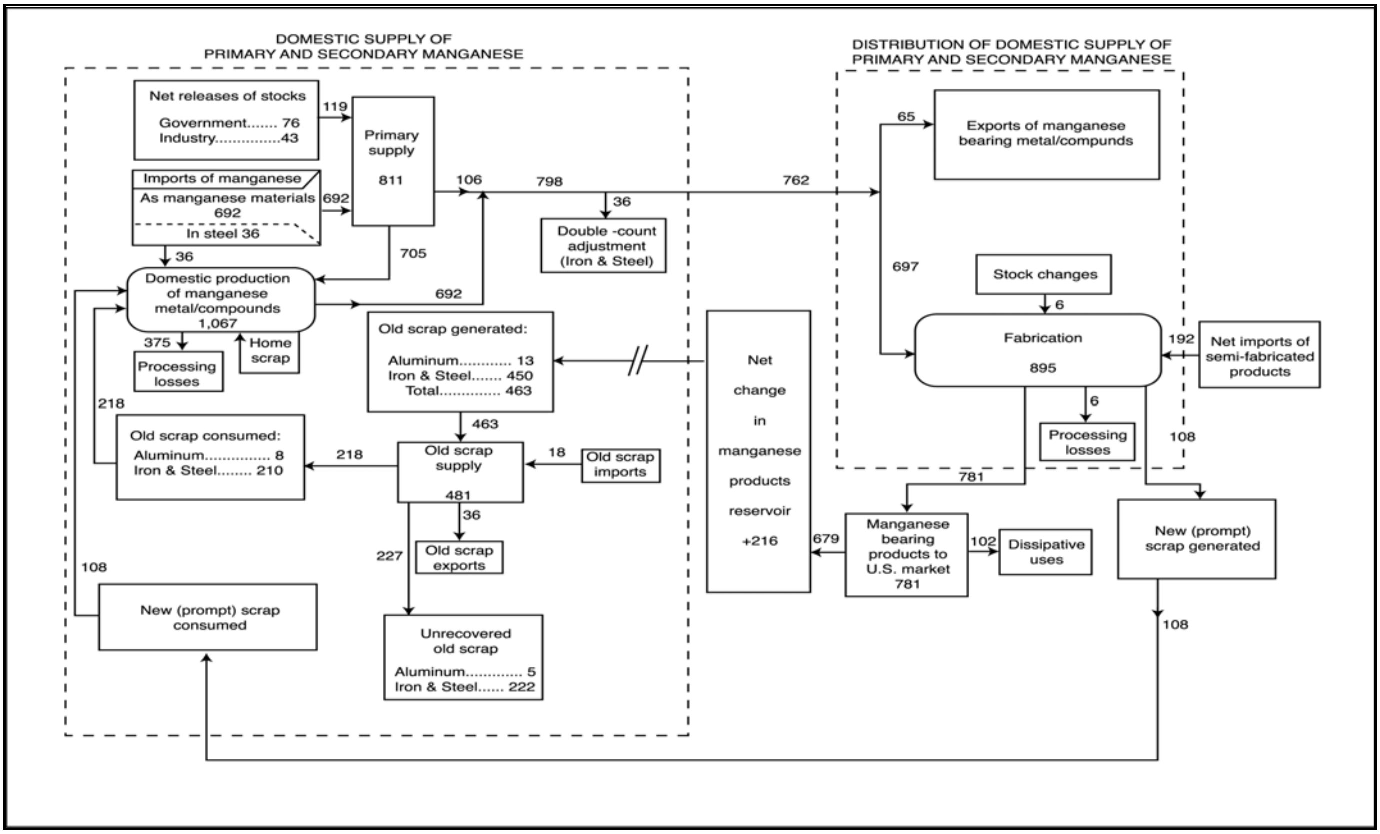

Figure 1. U.S. manganese materials flow, 1998. [Thousand metric tons, manganese content.]

The salient statistics for manganese-bearing scrap given in table 1 are based mainly on and determined by the status of recycling for iron and steel. The recycling of iron and steel scrap (ISS) is the subject of another report by the U.S. Geological Survey (USGS) (Fenton [in press]), to which the reader is referred for details. The aspects that deal with ISS are given only in summary form in this report. Two of the three ratios given in table 1 are nearly the same for manganese and ISS—old scrap recycling efficiencies of 53% for manganese and 52% for ISS, and new-to-old scrap ratios of 33 to 67 for manganese and 34 to 66 for ISS. The lower recycling rate for manganese (37%) than that for ISS (41%) reflects the relatively large loss of manganese during metallurgical processing. Figures given in table 1 for the value of the manganese units in scrap are based on a unit value of $560 per metric ton of manganese as estimated from foreign trade data for 1998.

The only significant metal form recovered specifically because of its manganese content was wear-resistant steel in which the manganese content typically is about 12% (so-called Hadfield steel). Otherwise, recovery of manganese in metal was incidental to the recycling of another metal—iron in the case of steel scrap and iron castings and aluminum in the case of used beverage cans (UBC's).

A small amount of manganese was recovered through recycling of dry cell batteries or manganese-bearing wastes generated in battery manufacture. One battery company formed a partnership with a steel company whereby more than 1,000 metric tons per year of scrap from the battery company was to be consumed in steel production (Watson, Andersen, and Holt, 1998). With a manganese content of 20%, this volume might be expected to contain about 200 metric tons (t) of manganese (Ferlay and Weill, 2000). Battery recycling is not considered further in this report because the quantity of manganese being recycled from batteries was relatively small and not precisely known.

SOURCES

Figure 1 is a composite derived from knowledge of the flows of manganese and manganese-bearing materials, such as ISS and aluminum UBC's. The data for the majority of the diagram are based on the material flow relations for ISS, in which the manganese content is taken as 0.6% throughout, as suggested by Jones (1994, p. 42), for average manganese content of steel. Scrap of high manganese (Hadfield) steel is not treated as a separate item. Its annual domestic production was not known but is estimated to be about

50,000 t as inferred from shipments (Kirgin, 2000). Even if it were recycled at a 75% rate, the manganese content of manganese steel scrap would only be about 2% of the estimated manganese content of the 35 million metric tons (Mt) of ISS consumed/recycled in 1998.

The inputs to primary supply of manganese as diagrammed in the upper left of figure 1 consist of drawdowns of industry and Government stocks of manganese materials, imports of manganese materials (ores, ferroalloys, metal, dioxide), and imports of raw steel. Of this, 4 units (4,000 t) of manganese exported as ore and 102 units of manganese destined for battery and chemical uses bypass metallurgical processing and flow directly to the output (right) side of the diagram. The balance of the primary supply goes mainly into the manufacture of ferroalloys and steel. Most of the ferroalloys and metal were used in steelmaking, but 31 units were exported and are included within the 65 units of exports.

The principal data sources are Fenton (2000b, c) and Jones (2000) in the 1998 USGS Minerals Yearbook or the sources upon which the data in these chapters are based. Quantities for manganese end uses are obtained from data collected by means of the Manganese Ore and Products survey of the USGS.

The types of manganese-bearing products ultimately becoming scrap and the industries in which they were used can be inferred by considering the pattern of manganese consumption. This is shown for 1979 through 1998 in figure 2, in which an estimated total of 730,000 t was used for 1997; this replaced the anomalously low published total of 643,000 t. Construction, machinery, and transportation have been the larger of the consuming sectors. The "All Other" category includes steel for nonspecified uses, as well as a number of other minor steel categories (appliances and equipment, cans and containers, and oil and gas industries).

OLD SCRAP GENERATED

Old scrap generated was mostly ISS. The first step in estimating this component was to assign lifetimes to various steel products as categorized in the steel shipments data published in the Annual Statistical Reports of the American Iron and Steel Institute. For ISS, the weighted average product life was 19 years. For each product, the quantity of steel becoming obsolete in 1998 was taken to be that shipped at the beginning of its life. For example, the quantity for a product with a lifetime of 20 years was the quantity of that product shipped in 1978.

Scrap from aluminum UBC's made only a small contribution to old scrap generated. Estimation of the addition to manganese recycling from UBC's is discussed in detail in the Processing of Manganese-Bearing Scrap section of this report.

NEW SCRAP

New scrap consists entirely of ISS that results from fabricating operations and is often returned directly from the fabricator to the originating steelplant. This type of scrap also is referred to as "prompt" or "prompt industrial" scrap and does not include home scrap, which stays within the plant or processing operation. The quantity of new scrap generated is taken as being equal to 15% of apparent consumption of steel (Fenton, [in press]). Apparent consumption of steel in 1998 was 118 Mt (Fenton, 2000a). The quantity of new scrap consumed is assumed to be equal to that generated, without losses or additions. As indicated in figure 1, the quantity of new scrap generated was about one-fourth that of the quantity of old scrap generated.

DISPOSITION

The supply of old scrap consists of old scrap from ISS plus a small amount of old scrap from UBC's (discussed later in the section on Used Aluminum Beverage Cans). As indicated in the left side of figure 1, the inputs to old scrap supply are quantity generated plus quantity imported. Output from old scrap supply includes exports and unrecovered scrap, with the balance going into current consumption (recycled). Import and export quantities are obtained from the trade statistics for ISS. The quantity consumed is obtained from ISS consumption data as provided by a USGS survey, from which is deducted the amounts of consumption of home and prompt scrap. The number of manganese units in the quantity consumed was 210,000 t. The amount of unrecovered scrap is estimated to be the difference needed to obtain a balance for supply of old scrap.

Also included in the right-hand portion of figure 1 is the dissipative loss of 102,000 t of manganese from the manufacture and use of manganese-containing batteries and chemicals. This was the quantity obtained for 1998 from the USGS Manganese Ore and Products survey of plants where EMD, batteries, or manganese chemicals (such as manganese sulfate and potassium permanganate) are made or which supplied manganese raw material that ultimately went into such items as animal feed and plant micronutrients. The battery total includes imports of manganese dioxide. The average lifetime of batteries and chemicals was assumed to be less than 1 year.

Table 1. Salient statistics for U.S. manganese-bearing scrap in 1998
[Values in thousand metric tons of contained manganese, unlessotherwise specified]

Old scrap:	
Generated[1]	463
Consumed[2]	218
Value of old scrap consumed	$120 million
Recycling efficiency[3]	53%
Supply[4]	481
Unrecovered[5]	227
New scrap consumed[6]	108
New-to-old scrap ratio[7]	33:67
Recycling rate[8]	37%
U.S. net exports of scrap[9]	18
Value of U.S. net exports of scrap	$10 million

[1] Old scrap theoretically becoming obsolete in the United States in 1998. Net U.S. imports of semifinished products containing manganese in 1998 are included. Dissipative uses are excluded.

[2] Old scrap recycled in 1998.

[3] (Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imports).

[4] Old scrap generated plus old scrap imports.

[5] Old scrap supply minus old scrap consumed minus old scrap exports.

[6] Including prompt industrial scrap but excluding home scrap.

[7] Ratio of quantities consumed, each measured in weight and expressed as a percentage of old plus new scrap consumed.

[8] Fraction of supply that is scrap on an annual basis. Old plus new scrap consumed divided by apparent supply [primary plus secondary production (old plus new scrap) plus imports minus exports plus adjustment for industry stock changes], in percent.

[9] Trade in scrap is assumed to be principally in old scrap.

RECYCLING EFFICIENCY FOR OLD SCRAP

Recycling efficiency is the amount of scrap recovered and reused relative to the amount available to be recovered and reused. The formula for calculating this ratio is given in footnote 3 of table 1, which, for the quantities specified in figure 1, becomes the sum of old scrap consumed plus old scrap exports divided by the sum of old scrap generated plus old scrap imports. These quantities pertain mostly to ISS plus a small component from UBC recycling. The percentage ratio so determined is 53%.

By using a different manganese material flow model, Gabler (1995, p. 19) estimated that for 1990 the amount of manganese contained in old scrap that was recycled corresponded to 12% of that year's apparent consumption. The equivalent percentage is 28% for the flow model for 1998 presented in figure 1.

Recycling of ISS and UBC's are well-established activities that have been going on for more than 200 years for ISS and for about 30 years for UBC's. Nearly one-half of domestic steel production in 1998 was from plants solely based on the use of scrap. Recycling efficiency is expected to remain about the same for ISS because of competition from alternative sources of iron units. The aluminum industry expects that the trend in recycling rate for UBC's will be for a slow but gradual increase.

INFRASTRUCTURE

No ore with a manganese content of 35% or more was mined domestically in 1998. Consequently, all primary units of manganese were obtained from either imported ore or ore released from Government stockpiles.

The chief facility where manganese was smelted and/or extracted was near Marietta, OH, and was the only site where manganese ferroalloys were produced domestically. In 1998, this facility, which was operated by Elkem Metals Co., accounted for more than 50% of total U.S. consumption of manganese ore. Ownership of this facility changed in 1999 to France's Eramet, and it was renamed Eramet Marietta Inc. In 2000, annual production of manganese ferroalloys there was given as 65,000 t for silicomanganese and a total

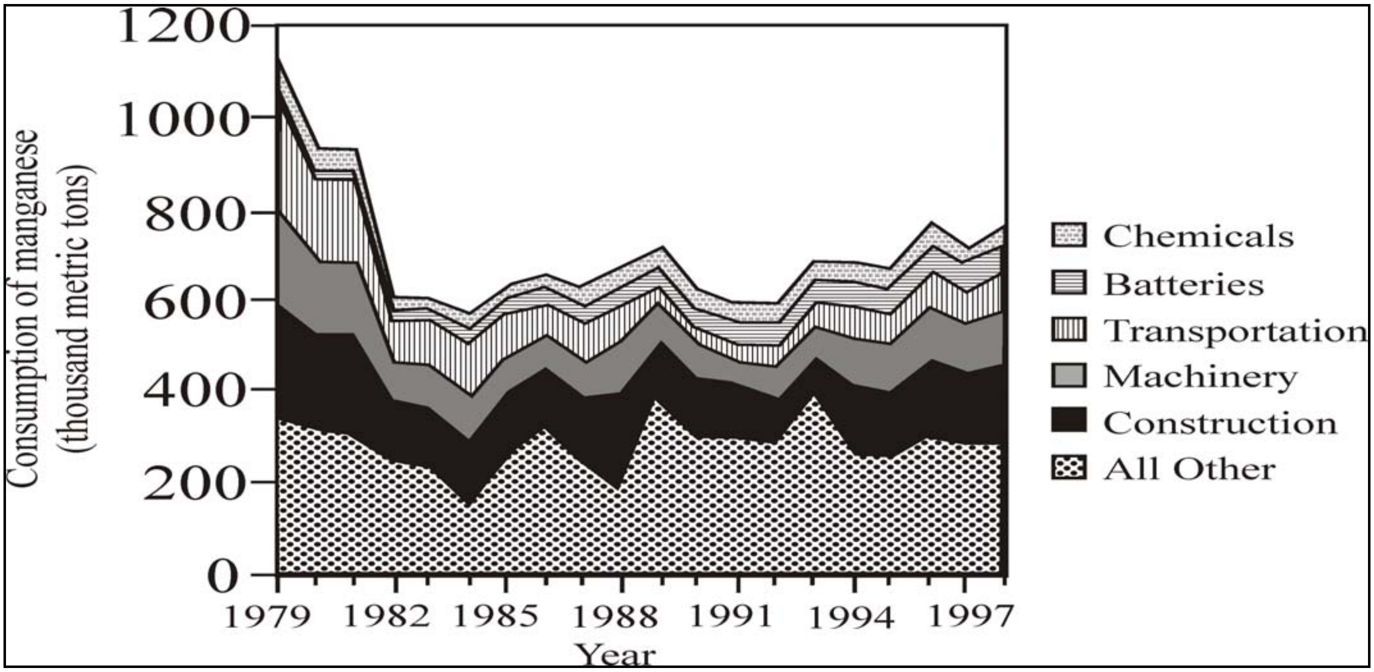

Figure 2. U.S. manganese end-use patterns, 1979-98.

of 104,000 t of various grades of ferromanganese (Platt's Metals Week, 2000); manganese metal and EMD also were produced electrolytically at this site. The EMD was produced by the Eveready Battery Co. Electrolytic metal was produced domestically at one other site that was in Nevada (Kerr-McGee Chemical LLC), and EMD, at two other sites, in Mississippi (also Kerr-McGee) and Tennessee (Chemetals Inc.). Subsequently, domestic production of manganese metal seemingly was ended permanently, first at Eramet Marietta in 2000 and then at Kerr-McGee in 2001.

Reports on recycling of iron and steel by Fenton (in press) and aluminum by Plunkert (in press) in this series of reports on mineral commodity recycling discuss the infrastructure for recycling of ISS and UBC's. In the case of ISS, this consists of a multitude of firms and facilities that are mostly in the northern and eastern parts of the country, within which is associated a large generation of scrap. Municipal collection programs play a principal role in the recycling of UBC's.

Monthly and annual reports of the USGS for Iron and Steel Scrap and for Aluminum provide details of foreign trade in scrap of these materials, especially trade of the United States. The United States historically has been a net exporter of ISS.

In chapter 81 of the Harmonized Tariff Schedule for U.S. imports, the portion that pertains to "Other base metals" contains a "Waste and scrap" sub-category (8111.00.3000) for manganese. The quantity of imports reported in this subcategory typically is about 200 t or less, most of which is from Canada. The nature of the material being reported under this subcategory is not well-known and probably consists of various manganese-bearing drosses, residues, and steel and/or iron items or perhaps none of these. This material is not included within the manganese materials flow discussed in this report except that the 215 t of so-called manganese waste and scrap reported as having been imported is assigned an average manganese content of 50% and, on that basis, is included within total manganese imports.

PROCESSING OF MANGANESE-BEARING SCRAP

SCRAP OF IRON AND STEEL

As indicated in the upper left-hand corner of figure 1, of the 811,000 t of manganese units from stocks and imports that comprise primary supply, 705,000 t goes into domestic production. Domestic production includes the sequence of manufacturing steps that produce manganese ferroalloys and/or metal, raw steel in whose manufacture domestic plus imported ferroalloys and metal are consumed, and finally steel mill shapes that are shipped to fabricators or end users. By means of a balance between the total inputs and outputs for production that relate to iron and steel, the metallurgical loss or nonutilization of manganese was calculated to be 368,000 t. This signifies a loss rate of 52%, which is somewhat greater than the range of 40% to 50% that is presumed to apply for manganese loss in steelmaking as of the 1990's (Jones, 1994, p. 15). The 52% figure does not seem unreasonable, however, when one considers that it includes not only losses in steelmaking, but also those in the manufacture of ferroalloys and metal. Presumably most of the manganese not ending up in product becomes a constituent of slag, at least some of which is usable.

Most of the processing of ISS takes place prior to its arrival at the steel plant. Operations at the steel plant consist of keeping scrap segregated according to its chemical and physical characteristics, plus cutting up bulky home scrap into more manageable pieces. Because of the high temperatures involved, ISS is completely melted in the steelmaking operation. Refining typically includes an oxidation step, as by injection of gaseous oxygen. This causes loss of carbon to gas and of some iron, manganese, and silicon to slag. The recycling model for iron and steel (Fenton [in press]) shows a processing loss for iron of 1 Mt, which is presumed to carry with it a manganese loss of 6,000 t, thus raising processing losses calculated so far to 374,000 t.

Small amounts of iron and steel are unrecoverably lost through such dissipative causes as corrosion. Some old scrap can be regarded as temporarily unrecovered through its disposal in landfills or abandonment in place. The manganese units in unrecovered ISS were estimated on the basis of the iron and steel model as 222,000 t.

Following this model, the amount of old scrap generated (i.e., the manganese content of the 75 Mt of iron and steel that became obsolete in 1998) was 450,000 t. As stated earlier in the section on Old Scrap Generated, the weighted average recycling time was 19 years. The material savings from recycling of ISS is estimated to be 1 t of iron ore and 0.6 t of coal per ton of scrap recycled. The energy saved from recycling of ISS was equivalent to that required to supply electricity to about one-fifth of domestic households (Fenton [in press]).

Home scrap within the steel plant is assumed, in view of its quality and known composition, to be recycled within 1 year of its generation. Similarly, new scrap generated during fabricating operations is relatively clean, of known composition, and requires little preparation. Consequently, prompt scrap, as implied by the term often used to refer to it, rapidly finds its way back to steel plants. This type of scrap is usually recycled directly, as from an automobile plant back to the steel plant from which the steel originally came.

USED ALUMINUM BEVERAGE CANS

Some of the quantities shown in figure 1 reflect the relatively small amounts of manganese recovered by recycling of UBC's. On a weight basis, aluminum beverage cans (ABC's) typically consisted 75% of bodies made from alloy 3004 and 22% of lids made from alloy 5182. The nominal manganese content of alloy 3004 is 1.1%, and that of alloy 5182 is 0.35%. The conditions for UBC recycling in 1998 were taken to be the same as those that have been projected for 1997—average UBC manganese content of 0.92% and melt loss of 9.3% (Sanders and Trageser, 1990, p. 197). Melt loss is the only source of manganese loss in UBC recycling, as there is essentially no loss of manganese due to burn-off or vaporization (R.E. Sanders, Jr., Technical Consultant, Aluminum Company of America, oral commun., December 4, 2000). UBC's were processed in facilities dedicated to their recycling.

The Aluminum Association estimated the net weight of new ABC's shipped in 1998 to be 3.09 billion pounds (1.4 Mt) and the rate of their recycling to be 62.8% (Aluminum Association, Inc., 1999). At 0.92%, the manganese content of the quantity shipped is approximately 12,900 t, which is assumed to be the quantity of old scrap eventually generated from this source. UBC recycling—from can shipment to use to disposal and recovery—takes place rather rapidly so that recovery is assumed to take place within the year of generation. At a recycling rate of 62.8%, the manganese content of the old scrap recovered (consumed) is 8,100 t. The unrecovered quantity of manganese is 4,800 (12,900 minus 8,100) t, or a rounded 5,000 t, which is only about 2% of total unrecovered old scrap. At a 9.3% melt loss rate, the loss in processing the 8,100 t of manganese recovered from UBC's in old scrap is about 750 t, or a rounded 1,000 t. Incorporation of this with the other losses already mentioned increases the total processing loss to 375,000 t.

SUMMARY AND OUTLOOK

Trends in recycling of manganese are largely determined by trends in recycling of iron and steel, which has been accounting for 85% to 90% of manganese consumption. Steel is the more-important industry with a production typically about 10 times that for cast iron. Consequently, the majority of manganese consumption is accounted for by production of raw steel (primary shapes).

The precipitous drop in manganese consumption between 1979 and 1982, which is shown in figure 2, is attributed mainly to two factors—a large decrease in raw steel production owing to adverse economic conditions and a significant decrease in the amount of manganese used per ton of steel produced. This decline in unit consumption was a gain from the adoption of new steelmaking technologies in the early 1980's, such as the use of combined blowing (Jones, 1994, p. 36). After 1983, the trend in total manganese consumption has been similar to that for raw steel production (about 1.8% per year growth). Assuming no significant change in manganese unit consumption, forecasts of the International Iron and Steel Institute suggest that the annual growth rate for total manganese consumption during the coming decade will be no greater than that of the past one (Iron & Steelmaker, 1999).

Figure 2 also shows that the distribution of manganese consumption among end uses has changed little with time. For the reasonably foreseeable future, the outlook is for this distribution pattern to remain about the same. Manganese consumption in batteries has been growing at a faster rate (about 6% per year) than steel-related uses but still accounts for less than 10% of total demand.

Recycling of ISS is a well-established component of domestic steel production. Supply of iron units for steel production now is about evenly divided between iron ore plus some scrap (integrated steelmaking) and all scrap except for a small proportion of direct-reduced iron [electric-arc furnace (EAF) mills]. In 2000, the EAF process was estimated to be used in 47% of domestic steel production. The share of domestic steel production taken by EAF mills has been growing steadily and is foreseen to be the dominant process by 2010 (Stubbles, 2000). This will provide the motivation for maintaining domestic recycling of manganese-bearing ISS.

On a much smaller scale, recycling of UBC's has reduced the primary manganese requirement for aluminum beverage cans. Recycling of household batteries, which is an activity that is in its infancy, has the potential to make a small contribution to manganese recycling. One of the original motivations for battery recycling—preventing mercury loss to the environment—has been greatly diminished because deliberate additions of mercury to the battery mix no longer are made.

From the standpoint of sustainable use of manganese, reducing manganese loss in metallurgical processing would appear to be a major subject for investigation and is always of interest as a way of cutting costs. The relations given in figure 1 indicate that almost one-half as much manganese is lost in metallurgical operations as is contained in products going into use. These relations also indicate that nearly 90% of metallurgical losses were compensated for by the level of scrap recycling. Efforts to recover manganese from steelmaking slags date back to at least World War II, but development of a commercially feasible method has not been achieved nor seems likely to be for the foreseeable future (Jones, 1994, p. 29). A major difficulty is that the manganese content of steelmaking slags is relatively low (typically 7% or less). Significant quantities of iron and steel slags are used in construction, road building, and for other purposes. These usages do not constitute a use of their manganese values per se.

REFERENCES CITED

Aluminum Association, Inc., 1999, Aluminum can recycling rate comes in at 62.8 percent for 1998: Washington, DC, Aluminum Association, Inc., press release, March 26, 1 p.

Fenton, M.D., 2000a, Iron and steel: U.S. Geological Survey Mineral Commodity Summaries 2000, p. 88-89.

———2000b, Iron and steel, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 1998, v. I, p. 39.1-39.15.

———2000c, Iron and steel scrap, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 1998, v. I, p. 40.1-40.19.

———in press, Iron and steel recycling in the United States in 1998: U.S. Geological Survey Circular.

Ferlay, Serge, and Weill, Patric, 2000, Used batteries—A global solution: ITE Letters on Batteries, New Technologies & Medicine (with News), v. 1, no. 4, p. 530-534.

Gabler, R.C., Jr., 1995, A manganese consumption and recycling flow model: U.S. Bureau of Mines Information Circular 9421, 50 p.

Iron & Steelmaker, 1999, Short- and medium-term outlook for steel demand: Iron & Steelmaker, v. 26, no. 12, p. 41-44.

Jones, T.S., 1994, Manganese material flow patterns: U.S. Bureau of Mines Information Circular 9399, 57 p.

———1999, Manganese, *in* Plunkert, P.A., and Jones, T.S., comps., Metal prices in the United States through 1998: U.S. Geological Survey, p. 83-86.

———2000, Manganese, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 1998, v. I, p. 49.1-49.17.

Kirgin, K.H., 2000, Total U.S. casting demand forecast to contract in 2000: Modern Casting, v. 90, no. 1, p. 30-33.

Platt's Metals Week, 2000, Eramet shuts US manganese metal production: Platt's Metals Week, v. 71, no. 30, July 24, p. 6-7.

Plunkert, P.A., in press, Aluminum recycling in the United States in 1998: U.S. Geological Survey Circular.

Sanders, R.E., Jr., and Trageser, A.B., 1990, Recycling of lightweight aluminum containers—Present and future perspectives, *in* van Linden, J.H.L., Stewart, D.L., Jr., and Sahai, Yogeshwar, eds., Recycling of Metals and Engineered Materials, 2nd, Williamsburg, VA, October 28-31, 1990, Proceedings: Warrendale, PA, The Minerals, Metals & Materials Society, p. 187-201.

Stubbles, John, 2000, EAF steelmaking—Past, present and future: Skillings Mining Review, v. 89, no. 43, October 21, p. 4-5.

Watson, N.J., Andersen, R.W., and Holt, G., 1998, Battery recycling in the metals industry from Europe to the USA, *in* International Seminar on Battery Waste Management, 10th, Deerfield Beach, FL, October 26-28, 1998, Proceedings: Boca Raton, FL, Florida Educational Seminars Inc., 7 p.

APPENDIX—DEFINITIONS

apparent consumption (AC). Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply (AS). AC plus consumption of new scrap (CNS).

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizer, making it exceptionally difficult and costly to recycle.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption; this includes all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities consuming old scrap. Included as new scrap is prompt industrial scrap—scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed in percent of new plus old scrap consumed (for example, 40:60).

old scrap. Scrap that includes, but is not limited to, metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, metals from shredded cars and appliances, silver from photographic materials, spent catalysts, tool bits, and used aluminum beverage cans. This is also referred to as "post-consumer scrap" and may originate from industry or the general public. Expended or obsolete material used dissipatively, such as paints and fertilizer, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as [consumption of old scrap (COS) + exports of old scrap (OSE)] divided by [old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks], measured in weight and expressed as a percentage; that is,

$$\frac{\text{COS + OSE}}{\text{OSG + OSI + decrease in OSS or - increase in OSS}} \times 100$$

old scrap supply. Old scrap generated plus old scrap imported plus old scrap stock decrease; that is, OSG + OSI + OSS decrease.

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase; that is, OSS - COS - OSS increase.

price. Based on unit value of contained manganese in materials.

recycling. Reclamation of a metal in useable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying (or other base metals) in steel; recovery of antimony in battery lead; recovery of copper in copper sulfate; and even the recovery of a metal where it is not desired but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and (or) tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap on an annual basis. It is defined as consumption of old scrap plus consumption of new scrap divided by apparent supply, measured in weight and expressed as a percentage; that is,

[(COS + CNS)/AS] x 100.

scrap consumption. Scrap added to the production flow of a metal or metal product.