

RECYCLING—METALS

BY STAFF

Introduction¹

Metals are important, reusable resources. Although the ultimate supply of metal is fixed by nature, human ingenuity helps to determine the quantity of supply available for use at any point in time by developing economic processes for the recovery of primary metal (i.e., from the Earth) and secondary metal (i.e., from the use/process stream). The reusable nature of metals contributes to the sustainability of their use.

Recycling, a significant factor in the supply of many of the metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of waste, and reduced emissions associated with energy savings. Table 1 lists salient U.S. apparent supply and recycling statistics for selected metals upon which the following comments are based. Metal apparent supply was 134 million metric tons (Mt) in 2002. Recycling contributed 74.8 Mt to metal apparent supply, an amount equivalent to 55.6% of metal apparent supply. Aluminum and iron and steel dominated the quantity of metal apparent supply and recycled material. By weight, iron and steel accounted for the largest share of metal apparent supply at 88.5% and the largest share of recycled metal at 92.3%. By weight, aluminum accounted for the second largest share of metal apparent supply at 6.00% and the second largest share of recycled metal at 3.91%. As measured by recycled metal as a percentage of apparent metal supply, lead was the most recycled metal at 71%, followed by iron and steel at 58%; the least recycled were tin at 20% and zinc at 26%.

Table 2 lists trade statistics for selected metals upon which the following comments are based. The United States exported 11.8 Mt of scrap metal valued at \$3.33 billion in 2002, while it imported 11.3 Mt of scrap metal valued at \$2.18 billion. Iron and steel dominated the quantity of exports at 77.4%; nickel and aluminum held distant second and third places at 9.09% and 5.21%, respectively, of quantity of metal exported. Iron and steel dominated the value of exports at 41.2%; aluminum, copper, and nickel held distant second, third, and fourth places at 18.1%, 15.3%, and 15.2%, respectively, of value of metal exported. Iron and steel dominated the quantity of imports for consumption at 90.9% and the value of imports for consumption at 61.6%. Aluminum was the second largest import at 4.11% of quantity of imports for consumption and 23.0% of value of imports for consumption.

This report summarizes metal recycling; however, individual annual reviews for each of the metals discussed in this report are in the respective chapters in this volume of the U.S. Geological Survey (USGS) Minerals Yearbook. Those reviews contain more detailed information about individual metals and recycling of those metals.

The term “primary” indicates material from ore deposits, and “secondary,” from recycled materials, including used products

and residual materials from manufacturing. Recycling practices and the description of those practices vary substantially among the metal industries covered in this report. Generally, scrap is categorized as “new” or “old,” where “new” indicates preconsumer sources, and “old” suggests postconsumer sources. The many stages of industrial processing that precede an end product are the sources of new scrap. For example, when metal is converted into shapes—bars, plates, rods, sheets, etc.—new scrap is generated in the form of cuttings, trimmings, and off-specification materials. When these shapes are converted to parts, new scrap is generated in the form of turnings, stampings, cuttings, and off-specification materials. Similarly, when parts are assembled into products, new scrap is generated. Once a product completes its useful product life, it becomes old scrap. Used beverage cans (UBCs) and junked automobiles and appliances are examples of old consumer scrap; used jet engine blades and vanes, junked machinery and ships, and metal recovered from commercial buildings or industrial plants are examples of old industrial scrap. A wide variety of descriptive terms, including home scrap, mill scrap, purchased scrap, prompt scrap, etc., have evolved to describe scrap generated by a wide variety of industry practices.

Aluminum²

Aluminum recovered from purchased scrap decreased slightly to 2.93 Mt in 2002. Of this recovered metal, 60% came from new (manufacturing) scrap, and 40% came from old (discarded aluminum products) scrap. Aluminum UBCs accounted for more than one-half of the reported old scrap consumption in 2002.

According to figures released by Aluminum Association Inc., the Can Manufacturers Institute, and the Institute of Scrap Recycling Industries, 53.8 billion aluminum UBCs was recycled in the United States in 2002, for a beverage can recycling rate of 53.4%. For 21 of the past 22 years, the rate has exceeded 50% (Aluminum Association Inc., 2003).

On March 4, the London Metal Exchange Ltd. (LME) launched a new aluminum alloy contract, the North American Special Aluminium Alloy Contract (NASAAC). It is a modified version of the LME alloy contract with a tighter A380.1 specification (Pinkham, 2002). Delivery points were limited to four U.S. warehouses—Baltimore, MD; Chicago, IL; Detroit, MI; and St. Louis, MO. At yearend 2002, these warehouses held 44,200 t of NASAAC ingot (London Metal Exchange Ltd., 2002). In June, the LME started cash trading for the NASAAC. The annual average NASAAC cash price for 2002, based on 6 months of trading, was 65.4 cents per pound.

Purchase prices for aluminum scrap, as quoted by American Metal Market, fluctuated but closed at higher levels than those at

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the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 51 to 52 cents per pound; old sheet and cast aluminum, 48 to 49 cents per pound; and clean, dry aluminum turnings, 48 to 49 cents per pound.

The aluminum producers' buying price range for processed and delivered UBCs, as quoted by American Metal Market, also closed higher at yearend. The price range began the year at 44 to 45 cents per pound and closed the year at 49 to 51 cents per pound. Resource Recycling published a monthly transaction price for aluminum UBCs in its Container Recycling Report. During the year, the monthly average fluctuated but closed higher at yearend. The January average was 47.3 cents per pound, and the December average was 52.4 cents per pound. The annual average transaction price for aluminum UBCs, however, decreased to 49.1 cents per pound in 2002 from 50.2 cents per pound in 2001.

The yearend indicator prices for selected secondary aluminum ingots, as published in American Metal Market, also increased compared with those at the beginning of the year. The closing prices for 2002 were as follows: alloy A380 (3% zinc content), 76.2 cents per pound; alloy B380 (1% zinc content), 77.6 cents per pound; alloy A360 (0.6% copper content), 80.5 cents per pound; alloy A413 (0.6% copper content), 80.5 cents per pound; and alloy 319, 79.1 cents per pound. Platts Metals Week published an annual average U.S. price of 70.2 cents per pound for A380 alloy (3% zinc content). The average annual LME cash price for a similar A380 alloy was 56 cents per pound.

Beryllium³

Beryllium is used in many applications where such properties as light weight and stiffness are important. In 2002, the United States, one of only three countries that processed beryllium ores and concentrates into beryllium products, supplied most of the rest of the world with these products.

U.S. apparent consumption of all beryllium materials was estimated to be about 180 metric tons (t) of contained beryllium in 2002 compared with about 230 t in 2001. The decline in consumption was owing in large part to soft demand from the telecommunications and computer markets. Beryllium-copper alloys are used in a wide variety of applications and account for the largest share of annual U.S. apparent consumption on a beryllium-metal-equivalent basis. Beryllium metal is used principally in aerospace and defense applications, and beryllium oxide serves mainly as a substrate for high-density electronic circuits. Because the cost of beryllium is high compared with that of other materials, it is used in applications in which its properties are crucial. Such substitutes as graphite composites, phosphor bronze, steel, and titanium are available for certain beryllium applications but can result in substantial loss in performance.

About 75% of domestic beryllium consumption was in the form of beryllium-copper alloys that are used mostly in electrical and electronic components. Little beryllium, however, was recovered from used products (old scrap) owing to the small size of the products, the difficulty in its separation, and the low

beryllium content in the alloys used; beryllium-copper alloys contain about 2% beryllium. Also, little beryllium metal old scrap was recycled; much of the metal was contained in nuclear reactors and nuclear weapons, which were difficult to recycle, and the beryllium contained may have been contaminated. Most of the recycling of beryllium-copper alloy old scrap products was undertaken to reclaim the copper value; the contained beryllium units were lost to the beryllium industry. Although little beryllium-bearing old scrap was recycled for its beryllium content, quantities of new beryllium-bearing scrap generated by fabricators from their machining and stamping operations were returned to beryllium producers for reprocessing. Detailed data on the quantities of beryllium recycled were not available but may comprise as much as 10% of U.S. beryllium apparent consumption (Cunningham, 2003a§⁴).

Cadmium⁵

The amount of secondary or recycled cadmium generated is difficult to estimate for several reasons. In the recycling of baghouse dusts from lead and copper smelters, for example, the recovered cadmium subsequently enters primary cadmium production circuits at zinc refining operations and is included in the production statistics for primary cadmium metal. There are no firm figures on the amounts of cadmium recovered from such sources as electroplating waste, filter cakes, sludges, and other cadmium-containing wastes. The total amount of cadmium recycled in 2002, as estimated by the International Cadmium Association, was about 10% of world primary production. Recycling of cadmium is a young and growing industry spurred by environmental concerns and regulatory moves to limit dissipation of cadmium into the ground from discarded cadmium products. Because about three-fourths of cadmium consumption is used in nickel-cadmium (NiCd) batteries and because batteries are easy to recycle, most of the secondary cadmium comes from spent NiCd batteries. Another form of old scrap that is easy to recycle is the flue dust generated during recycling of galvanized steel scrap in electric arc furnaces (EAFs). Most of the new scrap for recycling is generated during manufacturing processes, such as die casting. All other applications use materials that are low in cadmium content and, therefore, are difficult to recycle for cadmium. Consequently, much of this cadmium is dissipated.

In 2002, secondary cadmium production in the United States amounted to more than 300 t. International Metals Reclamation Co., Inc. (Inmetco) in Ellwood City, PA, is the only cadmium recycling company in the United States. Although Inmetco established the plant in 1978, cadmium recovery did not begin until 1996. Large batteries, usually weighing more than 2 kilograms (kg) and containing an average of 15% cadmium, are emptied of their electrolyte and dismantled (Morrow, 2000, p. 9). Detached cadmium plates then go directly into the furnace, using the high-temperature metal recovery process (HTMR). Cadmium in smaller sealed batteries is recovered by burning off the castings and separators at a lower temperature than used

⁴References that include a section mark (§) are found in the Internet References Cited section.

⁵Prepared by Jozef Plachy.

³Prepared by Larry D. Cunningham.

in the HTMR process. The resulting 99.95%-pure cadmium is shipped to battery manufacturers for reuse.

Chromium⁶

The major end use of chromium is in stainless steel, and this is the major form in which chromium is recycled. Chromite ore is smelted to make ferrochromium, a chromium-iron alloy that results from the removal of oxygen from chromite. Ferrochromium is then added to iron at steel-producing plants to make the iron-chromium alloy stainless steel. Stainless steel scrap can substitute for ferrochromium as a source of chromium. Stainless steel is composed of two broad categories—*austenitic* and *ferritic*. The names are related to the molecular structure of the steel but also identify which grades require nickel (*austenitic*) and which do not (*ferritic*). Nickel content increases the price of the alloy and its resulting scrap.

Scrap is generated during the manufacturing process (new scrap) and as a result of recycling obsolete equipment (old scrap). Scrap from these sources is collected and sorted by grade (i.e., chemical composition) in scrap yards. Scrap brokers play a role in moving material from where it is recovered to where it is consumed. The steel industry consumes stainless steel scrap as a source of chromium and nickel. Thus chromium units are recycled when stainless steel is reused. A study of domestic stainless steel found that its average chromium content is about 17% (Papp, 1991, p. 1). The USGS has published a detailed report on chromium recycling in the United States (Papp, 1999§).

Cobalt⁷

Cobalt-bearing scrap is generated during manufacture and/or following use in the following applications: catalysts used by the petroleum and chemical industries; cemented carbides used in cutting and wear-resistant applications; rechargeable batteries; and superalloys, magnetic and wear-resistant alloys, and tool steels. Depending on the type and quality of the scrap, it might be recycled within the industry sector that generated it, processed to reclaim the cobalt as a cobalt chemical or metal powder, downgraded by using it as a substitute for nickel or iron in an alloy with a lower cobalt content, or processed to an intermediate form that would then either be further refined or downgraded. The products of recycled cobalt scrap include alloys; mixed metal residues; pure cobalt metal, metal powder, or chemicals; and tungsten carbide-cobalt powders (Shedd, 2002§).

In 2002, scrap consumption reported by U.S. cobalt processors and consumers was 2,800 t of contained cobalt, basically the same as the 2,780 t (revised) consumed in 2001. The United States imported 224 t, gross weight, of cobalt waste and scrap, valued at \$1.8 million. Seven countries supplied 99% of this material—the United Kingdom (31%), Ireland (21%), Canada (19%), Brazil (10%), Japan (9%), Germany (5%), and France (4%). Imports of cobalt waste and scrap in 2002 are not comparable to those of previous years because, prior to 2002,

imports of cobalt waste and scrap were reported in combination with imports of cobalt metal powder. In 2002, the United States exported 107 t (gross weight) of cobalt waste and scrap valued at \$1.0 million. Most of this material was sent to Canada (58%), Belgium (18%), France (10%), Japan (8%), and Sweden (5%). Exports of cobalt waste and scrap in 2002 are not comparable to those of previous years because, prior to 2002, exports of cobalt waste and scrap were reported in combination with exports of unwrought cobalt metal and metal powders.

Columbium (Niobium)⁸

Columbium (also called niobium and indicated by the chemical symbol Nb) is a refractory metal that conducts heat and electricity well and is characterized by a high melting point, resistance to corrosion, and ease of fabrication. The principal use for columbium is in the form of steelmaking-grade ferrocolumbium. Ferrocolumbium is typically available in grades that contain 60% to 70% columbium. Steelmaking accounts for more than 80% per year of reported columbium consumption in the United States. Because of its refractory nature, appreciable amounts of columbium in the form of high-purity ferrocolumbium and nickel columbium are used in cobalt-, iron-, and nickel-base superalloys for such applications as heat-resisting and combustion equipment, aircraft engine components, and rocket subassemblies. Most columbium-containing superalloys contain up to 2% columbium; some cobalt- and nickel-based superalloys, however, contain up to 6% columbium. Acceptable substitutes, such as molybdenum, tantalum, titanium, tungsten, and vanadium, are available for some columbium applications, but substitution may lower performance and/or cost effectiveness.

In 2002, U.S. apparent consumption of all columbium materials was about 4,100 t compared with about 4,400 t in 2001. Columbium was mostly recycled from products of columbium-bearing steels and superalloys; little was recovered from products specifically for their columbium content. Although columbium is not recovered from the scrap steel and superalloys that contain it, recycling of these scrap materials is significant, and columbium content may be reused. Much of the columbium recycled in steel is diluted to tolerable levels; it effectively becomes a substitute for iron or other alloy metals rather than being used for its unique properties or is oxidized and removed in processing. New columbium-bearing scrap is generated mostly from manufacturing plants that produce steel products and fabricate parts made from superalloys. This type of scrap is usually quickly returned to steel plants and superalloy meltors for remelting. Detailed data on the quantities of columbium recycled are not available but may compose as much as 20% of U.S. columbium apparent consumption (Cunningham, 2003b§).

Copper⁹

According to data compiled by the International Copper Study Group (2003, p. 14-16), estimated world production of

⁶Prepared by John F. Papp.

⁷Prepared by Kim B. Shedd.

⁸Prepared by Larry D. Cunningham.

⁹Prepared by Daniel L. Edelstein.

secondary refined copper in 2002 rose nominally to 1.89 Mt from 1.86 Mt and accounted for 12.2% of global world refined copper production. Large declines in secondary production in Russia and the United States were more than compensated for by increased production in China, Germany, and Japan. According to data compiled by the World Bureau of Metal Statistics and adjusted by the USGS, an additional 3.7 Mt of copper was recovered from the direct melting of copper scrap, a decline of about 130,000 t from that of 2001 revised data (World Metal Statistics, 2003, p. 42). Secondary refined production in the United States continued its downward trend, declining by 102,000 t, or 59%, in 2002. Secondary refined production has fallen by about 325,000 t (82%) since 1997 owing to contraction of the secondary smelting/refining industry. Despite an almost 10% decline in refined copper consumption, copper recovered in alloys, chemicals, and powders from scrap (direct melt scrap) was essentially unchanged at 980,000 t.

Copper scrap prices generally followed the trend in refined copper prices. Tight supplies of scrap throughout the year, however, tended to lower the discount to refined copper. According to American Metal Market data, the discount from the New York Mercantile Exchange COMEX Division spot price for brass mill No. 1 scrap averaged only 1.4 cents per pound in 2002, down from 3.0 cents per pound in 2001. The upward trend in refined copper prices that began in mid-1999 stalled during the fourth quarter of 2000. Though prices rallied slightly at yearend 2001, they fell again in January 2002. A midyear rally saw the monthly average COMEX price rise to \$0.76 per pound before falling back. The average annual COMEX price fell to 71.7 cents per pound in 2002 from 72.6 cents per pound in 2001. The average annual discount to COMEX prices for No. 2 (refiners) scrap averaged 12.2 cents per pound, down from 13.6 cents per pound and 19 cents per pound, respectively, in 2001 and 2000.

According to data compiled by the International Copper Study Group (2003, p. 40-43), global trade in copper scrap, based on reported exports of 2.75 Mt, was down slightly in 2002. Though total scrap exports from the United States declined by 23,000 t to 511,000 t, the United States remained the largest source of scrap, accounting for 18.5% of global scrap trade. Russia, which in 1998 had exported 357,000 t of scrap, mostly to Europe, exported only about 8,000 t in 2002. China (including Hong Kong), which reported copper scrap receipts of 3.15 Mt, down from 3.43 Mt in 2001, was the largest recipient of scrap and was the destination for 57% of U.S. scrap exports. Note, however, that data on world scrap trade are incomplete, with reported imports generally exceeding reported exports. In 2002, U.S. imports of copper scrap of 100,000 t were down from 115,000 t in 2001. Canada and Mexico were the leading sources for U.S. imports of copper and copper alloy scrap, accounting for 64% of imports in 2002.

During 2002, three fire refineries processed scrap to recover unalloyed copper products in the United States. Scrap was also consumed in relatively small quantities at several of the primary smelters. Chemetco Inc., which operated the last remaining U.S. secondary smelter, closed in October 2001 and remained shuttered throughout 2002. The closure of Chemetco, which had the capacity to produce 135,000 metric tons per year (t/yr) of anode for electrolytic refining and reduced production at one

fire refinery that operated intermittently throughout the year, accounted for the large drop in secondary refined copper output.

Direct melt scrap, principally alloy scrap, was consumed at about 30 brass mills; 20 alloy ingot makers; and 500 foundries, chemical plants, and miscellaneous consumers. Of the 1.05 Mt of copper recovered from aluminum, copper, nickel, and zinc base scrap, brass mills recovered 70%; brass and bronze ingot makers, 11%; copper smelters and refiners, 7%; and miscellaneous manufacturers (including aluminum and steel alloy producers), foundries, and chemical plants, 12%. Alloyed copper products accounted for about 93% of the total copper recovered from scrap.

In 2002, copper recovered from all refined or remelted scrap (about 80% from new scrap and 20% from old scrap) composed 30% of the total U.S. copper supply and had an equivalent refined value of \$1.75 billion. The conversion of old scrap to alloys and refined copper declined for the fifth consecutive year, falling by 110,000 t (35%) to 207,000 t. Lower copper prices in 2002 and secondary copper smelter and fire refinery closures led to the continued downward trend in recovery. Copper recovered from new scrap (842,000 t) rose nominally despite continued weak reports by brass mills, the prime consumer of new scrap.

As evidence of continued weak U.S. demand for copper mill products, several companies announced yearend cutbacks. Cerro Metal Products Co. announced the closure of its Paramount, CA, brass mill at the end of November. The plant produces brass bar, rod, shapes, and wire and was a consumer of yellow brass scrap. The company reportedly will continue to supply the Western United States from its Bellefonte, PA, plant (Platts Metals Week, 2002a). In mid-December, Olin Corporation (2002) announced that it was considering the possible closure of its brass manufacturing facility in Indianapolis, IN, owing to weak market demand for copper alloy sheet and strip products. In January 2003, Olin announced that it had decided to close the plant, and owing to capacity additions at its East Alton, IL, facility, the company had sufficient capacity to meet customer needs. Closure was anticipated to be completed by the end of the first quarter of 2003 (Olin Corporation, 2003). The plant had been shuttered or operating at significantly reduced capacity for the 5-month period ending in May 2002.

Gallium¹⁰

Because of the low yield in processing gallium to optoelectronic devices or integrated circuits, substantial quantities of new scrap are generated during the various processing stages. These wastes have varying gallium and impurity contents, depending upon the processing step from which they result. Gallium-arsenide (GaAs)-based scrap rather than metallic gallium represents the bulk of the scrap that is recycled. During the processing of gallium metal to a GaAs device, waste is generated in several stages. If the ingot formed does not exhibit single crystal structure or if it contains excessive quantities of impurities, the ingot is considered to be scrap. Some GaAs also remains in the reactor after the

¹⁰Prepared by Deborah A. Kramer.

ingot is produced; this GaAs can be recycled. During the wafer preparation and polishing stages, significant quantities of wastes are generated. Before wafers are sliced from the ingot, both ends of the ingot are cut off and discarded because impurities are concentrated at the one end of the ingot and crystal imperfections at the other end. These ends represent up to 25% of the weight of the ingot. As the crystal is sliced into wafers, two types of wastes are generated—saw kerf, which is essentially GaAs sawdust, and broken wafers. When the wafers are polished with an abrasive lapping compound, a low-grade waste is generated. During the epitaxial growth process, various wastes are produced, depending on the growth method used. Because GaAs is a brittle material, wafers may break during the fabrication of electrical circuitry on their surfaces. These broken wafers also can be recycled. Gallium content of these waste materials varies from less than 1% to as much as 99.99%. In addition to metallic impurities, the scrap may be contaminated with other materials introduced during processing, such as glass, plastics, silicone oils, water, and waxes (Kramer, 1988, p. 15).

In processing GaAs scrap, the material is crushed if necessary, then dissolved in a hot acidic solution. This acid solution is neutralized with a caustic solution to precipitate the gallium as gallium hydroxide, which is filtered from the solution and washed. The gallium hydroxide filter cake is redissolved in a caustic solution and electrolyzed to recover 99.9% to 99.99% gallium metal (Kramer, 1988, p. 15).

In addition, a pilot process was developed to process GaAs scrap by liquid ion extraction to recover gallium that is up to 99.99999% pure. Met-Tech Systems Inc., Mississauga, Ontario, Canada, built its first full-scale plant for recovery of gallium from semiconductor industry scrap material. The basic process steps involved grinding of the scrap, multistage solvent extraction, and electropurification. (The purification process has been patented.) Purity of the gallium product was expected to be at least 99.99999%. The company claimed that with this technology nearly 100% of the gallium content of the recycled scrap material could be recovered from almost any scrap stream (Ontario Centre for Environmental Technological Advancement, 2000§).

Under a cooperative agreement with the U.S. Environmental Protection Agency (EPA), researchers at the University of Dayton Research Institute developed two processes to recover gallium and arsenic from GaAs wastes. The first process involved the thermal separation of GaAs solid wastes into their constituent elements (with a minimum of energy input or additional handling). Each of the separated elements was then purified to the required levels for further crystal growth using low-cost procedures. A second process was developed for the recovery of both arsenic and gallium from GaAs polishing wastes. The second process involved removing the majority of the arsenic and suspended polish as a mixed precipitate of calcium arsenate and polish. This first process step was performed at ambient temperatures and at a pH greater than 11 using sodium hydroxide. At this pH, gallium was retained in solution in the form of sodium gallate. Precipitation of almost pure gallium hydroxide was accomplished in the next step through a pH adjustment to between 6 and 8 with waste acids (Swartzbaugh and Sturgill, 1998§).

Some GaAs manufacturers may recycle their own scrap or scrap may be sold to metal traders, to a company that specializes in recycling GaAs, or to the GaAs manufacturer's gallium supplier, who can recover the gallium and return it to the customer. Generally the prices commanded by GaAs scrap parallel the price fluctuations of 99.99%-pure gallium metal. Also, prices are dependent on the type and gallium content of the scrap. GaAs scrap that is recycled is new scrap, which means that it has not reached the consumer as an end product, and it is present only in the closed-loop operations between the companies that recover gallium from GaAs scrap and the wafer and device manufacturers (Kramer, 1988, p. 15).

Excil Inc., a firm that reclaims silicon wafers, announced that it has the capability to reclaim 4- and 6-inch GaAs wafers. The company chemically strips and etches the surface of a wafer that has surface defects, then polishes the wafer to remove trace contaminants to meet customers' specifications. The company claims that its reclaimed 6-inch wafers, which cost \$85 to \$100 each, will be more economical than purchasing prime-grade wafers at \$350 to \$400 each or mechanical-grade, costing \$175 to \$250 per wafer (Excil Inc., undated§).

Gold¹¹

Old scrap consists of gold-containing products that have been discarded after use, and generally contributes 13% to 25% of the total U.S. supply of gold. New scrap is generated during manufacturing processes and, for the most part, remains the property of the manufacturers; it is not counted as part of the market supply. The scrap component of the gold supply is perhaps the most difficult of all metal supply components to quantify. In many areas of the world, especially in those areas where the holding of gold is encouraged by tradition, secondary gold, especially that derived from gold jewelry, changes hands both locally and internationally, often using goldsmiths as collection sites. This flow is often in response to variations in the gold price and usually cannot be followed statistically.

A considerable quantity of scrap is generated during manufacturing, but because of tight controls over waste materials in precious metals plants, nearly all of this "home generated" scrap can be recovered. Probably the greatest loss in gold fabrication takes place in gold-plating plants where fouled or depleted solutions are sometimes discarded. Some old scrap, however, is lost because, in practice, gold cannot be economically recovered from all manufactured products. Gold-bearing scrap is purchased on the basis of gold content, as determined by analytical testing and the market price for gold on the day that the refined product is available for sale. Processing charges and adjustments for processing losses are deducted from the total value in settling payments. Aside from dealer-processors and refiners, scrap gold has no market. The Federal Trade Commission requirement for karat identification of jewelry alloys requires gold refiners to identify the chemical analysis of the alloys they purchase and to separate the constituents of scrap to assure meeting karat standards [Public Law 226, An act forbidding the importation, exportation, or carriage in interstate commerce of falsely or spuriously stamped

¹¹Prepared by Earle B. Amey.

articles of merchandise made of gold or silver or their alloys, and for other purposes, 1906, 59th Congress, 1st Session, Revised Statute U.S. v. 34, part 1, June 13, p. 260]. Refiners throughout the world recover secondary gold from scrap. In the United States, about two-thirds of the scrap comes from manufacturing operations, and the remainder comes from old scrap in the form of such items as discarded jewelry and dental materials, junked electronic equipment, and used plating solutions. A few dozen companies, out of several thousand companies and artisans, dominate the fabrication of gold into commercial products. Most of the domestic scrap is processed by refiners centered in New York, NY, and Providence, RI; refiners are also concentrated in areas of California, Florida, and Texas, although the current trend seems to be toward a less centralized industry. Scrap dealers may process the scrap and then ship the upgraded product to refiners and fabricators for further treatment and refining. The U.S. Department of Defense (DOD) has recovered significant quantities of gold from military scrap (Laura Green, Precious Metals Specialist, Defense Logistics Agency, oral commun., 1998). Other Federal Government agencies either participate in the DOD recovery program or have one of their own. The DOD awarded contracts to manage more than 11 million kilograms of electronic scrap that was collected through the middle of 2000 (American Metal Market, 2000).

Domestic consumption of old and new gold scrap was 56,000 kg and 45,000 kg, respectively, in 2002. These data, which were collected by the USGS, included 12,000 kg of old imported scrap. In 2002, U.S. exports of gold scrap increased by 113%, while imports decreased by 55%. As it has been for many years, the United States was a net exporter of gold scrap in 2002. In 2002, the unit value of imported waste and scrap gold was \$194 per troy ounce, and exported, \$184 per ounce; the average price was \$311 per ounce (Platts Metals Week, 2003).

Indium¹²

Recycling of indium scrap continued to increase, but not enough to offset the decline in primary production. World reserves, which are based on estimated indium content of zinc reserves, are sufficient to meet anticipated demand for at least 10 years at levels slightly above current world consumption. This projection assumes that almost one-half of the world's indium supply will result from recycling of existing materials.

The EPA introduced a procedure for simplifying the recycling of cathode ray tubes (CRTs) as a regional experiment at the end of December 2002. This recycling experiment was then stopped early in 2003 to allow further study on the recycling of electronic components. Advocacy groups argued that individual scrap yards would not be able to guarantee the material's final destiny when selling to brokers or larger yards. Much of the debate now hinges on the export of recyclable scrap to foreign entities that do not maintain adequate hazardous material dismantling facilities (Schaffer, 2003).

An estimated 37 t of indium is contained as flue dust at a site in Kellogg, ID, where Bunker Hill Company once operated a lead and zinc smelter (Platts Metals Week, 2001). Shortly after closure of the smelter, the EPA declared it to be a

Superfund site under regulations that cover nonoperating sites with environmental problems that require cleanup. Although some firms have made contract bids on the cleanup of the smelter site, none have submitted a proposal that would fulfill the environmental requirements (Cami Grandinetti, U.S. Environmental Protection Agency, written commun., October 24, 2002).

A key issue on the supply side will be the ability of individual countries to recycle the indium-containing electronic components, which tend to have a short obsolescence cycle. Japan and other East Asian countries appear to be at the forefront of recycling efforts. Recent trends in indium price combined with the curtailment of primary refining capacity have added an extra incentive to the recovery of secondary indium. Sustained prices in the \$160-to-\$200-per-kilogram range will encourage increased recycling and primary production (Metal-Pages, 2003§). Japanese production of new indium by Dowa Mining Co., Ltd. and Nippon Mining & Metals Co., Ltd. remained stable at between 50 and 55 t/yr for the past several years and continued to remain so in 2002. With the decline in Japanese zinc refining, an aggressive recycling program was expected to make up for any shortfalls in Japanese domestic production (Roskill's Letter from Japan, 2003).

In the United States, only small amounts of new indium scrap were recycled in 2002. This is because the infrastructure for collection of indium-containing products is not well established in the United States and because the low price of primary indium has not economically warranted its development. Recycling of indium could expand significantly in the United States if the price of indium continues to increase. About 60% of the indium-tin oxide scrap could be reused should the price of indium warrant increased recycling.

Iron and Steel¹³

Iron, including its refined product steel, is the most widely used of all the metals, and the recycling of iron and steel scrap (ferrous scrap) is an important activity worldwide. Iron and steel products are used in many construction and industrial applications, such as in appliances, bridges, buildings, containers, highways, machinery, tools, and vehicles. Because it is economically advantageous to recycle iron and steel by melting and recasting into semifinished forms for use in the manufacture of new steel products, a significant industry has developed to collect old scrap (used and obsolete iron and steel products) and new scrap (the ferrous scrap generated in steel mills and steel-product manufacturing plants). The North American steel industry's overall recycling rate is 71% (American Iron and Steel Institute, 2003).

The vast quantity of ferrous scrap available for recycling comprises home, obsolete, and prompt scrap. Prompt, or industrial, scrap is generated from manufacturing plants that make steel products. Its chemical and physical characteristics are known, and it is usually transported quickly back to steel plants for remelting to avoid storage space and inventory control costs. Home, or mill, scrap is generated within the steel mill during production of iron and steel. Trimmings of mill products

¹²Prepared by John D. Jorgenson.

¹³Prepared by Michael D. Fenton.

and defective products are collected and can be quickly recycled back into the steel furnace because their chemical compositions are known. The availability of home scrap has been declining because new and more efficient methods of casting have been adopted by the industry. Obsolete, old, or postconsumer scrap is also available for recycling and is a major source of scrap steel. The largest source is junked motor vehicles, followed by demolished steel structures, worn out railroad cars and tracks, appliances, and machinery. Because of the wide variety of chemical and physical characteristics, obsolete scrap requires more preparation, such as sorting, detinning, and dezincing.

In the United States, discarded automobiles are the single most important source of obsolete steel (Rich Tavoletti, Marketing Manager, American Iron and Steel Institute, unpub. data, July 2002). Of the ferrous metals used to make a typical 2001 U.S. family vehicle, 45% was recycled metal. About 12,000 car dismantlers and 3,000 scrap processors produced about 13.9 Mt of iron and steel scrap for recycling in 2001—enough steel to produce more than 14 million new cars. The recycling rate of automobile scrap steel was 101% in 2002 compared with 102% in 2001. A recycling rate greater than 100% is a result of the steel industry recycling more steel from automobiles than was used in the production of new vehicles.

Manufactured steel products have a wide range of physical and chemical characteristics according to the relative content of the steel accounted for by the trace elements carbon, chromium, cobalt, manganese, molybdenum, nickel, silicon, tungsten, and vanadium. Also, some steel products are coated with aluminum, chromium, lead-tin alloy, tin, or zinc. For these reasons, scrap dealers must carefully sort the scrap they sell, and steelmakers must be careful to purchase scrap that does not contain undesirable elements, or residuals, that exceed acceptable levels, which vary according to the product being produced.

Steel mills melt scrap in basic-oxygen furnaces (BOFs), EAFs, and to a minor extent, in blast furnaces. The proportion of scrap in the charge placed in a BOF is limited to less than 30%, whereas that in an EAF can be as much as 100%. Steel and iron foundries use scrap in EAFs and cupola furnaces. In 2002, BOFs were used to produce 50% of total steel in the United States while using only about 25% of total scrap consumed (American Iron and Steel Institute, 2003, p. 86). During the same period, EAFs produced 50% of total steel while using about 75% of total scrap consumed. Compared with the amount of scrap used in BOFs and EAFs, a statistically insignificant amount of scrap was also melted in blast furnaces and other types of furnaces.

Iron and steel scrap is an additional resource for steelmakers that is more than just economically beneficial. Recycling also conserves energy, landfill space, and natural resources. For example, recovery of 1 t of steel from scrap conserves an estimated 1,134 kg of iron ore, 635 kg of coal, and 54 kg of limestone needed to produce a single ton of primary steel. In addition, steel recycling each year saves the energy equivalent to electrically power about one-fifth of the households in the United States (about 18 million homes) for 1 year (Steel Recycling Institute, 2001§).

During 2002, steel recycling rates were 101% for automobiles, 95% for construction structural beams and plates, 87% for appliances, 57% for steel cans, and nearly 71% overall (American Iron and Steel Institute, 2003§). Ferrous scrap is

an important raw material for the steel and foundry industries. Because scrap comes from such sources as old buildings, discarded cars and consumer durables, industrial machinery, and manufacturing operations, the mature, industrialized nations are the main exporters of scrap.

The main trade flows of scrap are from the heavily industrialized and developed countries of North America and Europe to lesser developed steelmaking countries. The United States was the leading exporter of iron and steel scrap in 2001, as reported by the International Iron and Steel Institute (2002, p. 102), followed by Germany, Japan, Russia, the United Kingdom, France, and Ukraine. The most significant importing nations, in decreasing order of importance, were China, the Republic of Korea, Spain, Belgium and Luxembourg, and Turkey (International Iron and Steel Institute, 2002, p. 104).

The U.S. trade surplus for all classes of ferrous scrap was 5.7 Mt in 2001 (U.S. Census Bureau, unpub. data, 2002). Total U.S. exports of carbon steel and cast-iron scrap went to 65 countries and totaled 8.0 Mt. The largest tonnages went to China, the Republic of Korea, Mexico, and Canada. Total U.S. exports of stainless steel scrap went to 46 countries and consisted of 343,000 t. The largest tonnages went to Taiwan, the Republic of Korea, China, Canada, and Spain. U.S. exports of alloy steel scrap (excluding stainless steel) were shipped to 47 countries and totaled 707,000 t. The largest amounts went to China, Mexico, and Canada.

Lead¹⁴

About 81% of the 1.37 Mt of refined lead produced in the United States in 2002 was recovered from recycled scrap, of which a major source was spent lead-acid storage batteries. The recycled batteries consisted of the starting-lighting-ignition type used in automotive applications as well as the industrial-type used in numerous applications, such as airport ground-support equipment, floor sweepers/scrubbers, golf cars and other human and materials transport vehicles, industrial forklifts, lawn equipment, load-leveling equipment for commercial electrical power systems, mining vehicles, and uninterruptible power-supply. About 6% of the recycled lead was recovered from other lead-based sources, including building construction materials, cable covering, drosses and residues (new scrap) from primary smelter-refinery operations, and solder.

Fifteen companies operating 23 lead recovery plants produced recycled lead domestically. Of the 1.10 Mt of lead recycled in 2002, about 99% was produced by 7 companies operating 15 secondary smelter-refineries in Alabama, California, Florida, Indiana, Louisiana, Minnesota, Missouri, New York, Pennsylvania, Tennessee, and Texas. Most of the recycled lead was recovered either as soft lead or lead alloys to be reused in the manufacture of lead-acid storage batteries. Consumption of lead in storage batteries accounted for 83% of the reported consumption of lead in the United States in 2002.

During 2002, the United States exported about 119,000 t of lead-bearing scrap, which included whole spent lead-acid batteries as well as nonbattery forms. Imported lead-bearing

¹⁴Prepared by Gerald R. Smith.

scrap in all forms totaled about 2,600 t during the year.

The recovery of lead from spent lead-acid batteries and other lead scrap at secondary smelters in 2002 was sufficient to meet about 89% of the demand for lead in the manufacture of new batteries. The market price for undrained whole scrap batteries averaged about 3.5 cents per pound at the end of 2002, translating to a lead price of 7.0 cents per pound, assuming that lead accounted for about 50% of battery weight. Soft lead scrap averaged 6.0 cents per pound and mixed hard lead and wheel weights averaged 8.5 cents per pound at yearend 2002 (American Metal Market, 2002c). The average price for refined lead produced at secondary smelters in 2002 was about 45 cents per pound (Platts Metals Week, 2003). The failure rate of automotive batteries increased during the early months of the year as a result of sustained winter temperatures extreme in some regions of the United States. However, the demand for lead in the production of new replacement batteries remained soft, largely due to continued depletion of existing replacement battery inventories. Demand for lead in the production of replacement batteries continued at a level pace for the remainder of the year. Production of refined lead recycled from old scrap increased by about 3% in 2002 compared with production in 2001. Stocks of refined secondary lead held by producers and battery manufacturers increased by about 5% at yearend 2002 compared with those of yearend 2001.

At yearend 2002, East Penn Manufacturing Co., Inc., Lyon Station, PA, announced plans to significantly increase its secondary lead production capacity. The permitting process for the construction of two reverberatory furnaces as well as a blast furnace reportedly was initiated. The additional units would effectively increase East Penn's secondary lead production capacity to about 145,000 t/yr from the current level of about 82,000 t/yr. According to East Penn, the units were not likely to be operational until 2005. The expansion is expected to significantly reduce the company's current reliance on other North American secondary producers to process a portion of the battery scrap received through its battery manufacturing and battery return program (Ryan's Notes, 2002).

Exide Technologies Inc., Princeton, NJ, a major producer of recycled lead and a manufacturer of lead acid batteries, received approval in May from the U.S. Bankruptcy Court in Delaware to use its \$250 million debtor-in-possession (DIP) financing facility. The DIP financing was used to fund operations and pay obligations to employees and suppliers (American Metal Market, 2002a). Exide Technologies and its three U.S. subsidiaries—Exide Delaware, Exide Illinois, and Royal Battery Distributors—had filed for Chapter 11 bankruptcy protection on April 15. The company, at that time, had arranged for additional financing, which would allow it to continue normal operations subject to court approval (Metal Bulletin, 2002).

Magnesium¹⁵

New magnesium-base scrap typically is categorized into one of six types. Type 1 is high-grade clean scrap, generally such material as drippings, gates, and runners from die-casting

operations that is uncontaminated with oils. Type 2 is clean scrap that contains steel or aluminum, but no brass or copper. Type 3 is painted scrap castings that may contain steel or aluminum, but no brass or copper. Type 4 is unclean metal scrap that is oily or contaminated. Type 5 is chips, machinings that may be oily or wet, or swarf. Type 6 is residues (crucible sludge, dross, etc.) that are free of silica sand. The most desirable type of scrap is type 1. Most of the type 1 scrap is generated during die-casting magnesium alloys; this typically represents 40% to 60% of the total cast weight, most of which consists of runners that feed the die cavity as it is injected with magnesium (Magnesium Elektron Ltd., 1999a§, b§). This scrap is either reprocessed at the die-casting facility or sold to a scrap processor. The other types of scrap are either sold to a scrap processor or are used directly in steel desulfurization. Old magnesium-base scrap, or postconsumer scrap, consists of such material as automotive parts, helicopter parts, lawnmower decks, used tools, and the like. This scrap is sold to scrap processors.

In addition to magnesium-base scrap, significant quantities of magnesium are contained in aluminum alloys that also can be recycled. Although some magnesium is lost in scrap processing, a significant quantity of the magnesium is recycled with the aluminum alloy. New aluminum-base scrap that is recycled primarily consists of, in descending order of importance, solids, borings and turnings, dross and skimmings, and other material, which includes foil and can-stock clippings. Because the main aluminum product that contains magnesium is beverage cans, the principal magnesium-containing aluminum-base scrap is can-scrap skeleton from lids and can sheet clippings. This represents about one-half of the overall magnesium-containing aluminum-base scrap.

Old aluminum-base scrap consists of a variety of materials, but the most important magnesium-containing component is UBCs. Because of the high recycling rate, UBCs represent about three-quarters of the magnesium-containing, old aluminum-base scrap that is reprocessed. The magnesium in old and new aluminum-base scrap is not separated from the aluminum alloy when it is recycled; rather, it is retained as an alloying component.

Magnesium scrap arrives at the recycler either loose on a dump trailer or in boxes on a van-type trailer. Sorting the magnesium-base scrap correctly is crucial to producing a product that meets specifications. Because magnesium and aluminum closely resemble each other, a load of magnesium scrap may contain some aluminum scrap as well. The scrap is visually inspected, and one of the ways to identify the magnesium from the aluminum scrap is by scratching the metal with a knife. Magnesium tends to flake, whereas the softer aluminum tends to curl. After separating the aluminum-base scrap and any other foreign material, the magnesium scrap is sorted according to alloy. In melting, sorted scrap is charged to a steel crucible, which is heated to 675° C. As the scrap at the bottom begins to melt, more scrap is added. The liquid magnesium at the bottom is covered with a flux or inhibitive gas to control surface burning. After alloying elements, such as aluminum, manganese, or zinc, are added and melting is complete, molten magnesium is transferred to ingot molds by hand ladling, pumping, or tilt pouring (Wentz and Ganim, 1992).

¹⁵Prepared by Deborah A. Kramer.

In addition to melting, magnesium scrap may be recycled by direct grinding of the scrap into powder for iron and steel desulfurization applications. This method is limited to using only specific types of clean scrap. Drosses and other contaminated scrap are not used because they can introduce impurities into the finished product, and these types of scrap can increase the danger of fire in the direct grinding (Dahm, 2000).

Pechiney officially closed the primary production portion of its Marignac, France, plant on July 2; the company had not produced any magnesium since June 2001. The company began converting the plant into a 5,000-t/yr magnesium recycling operation, which would produce niche products, including turnings and granules. Pechiney was expected to source the scrap feedstock from France, Italy, and Spain (Platts Metals Week, 2002b).

Remag Alloys BV planned to construct a 10,000-t/yr magnesium recycling plant in Delfzijl, Netherlands, with production to start about October 2003. Raw material for the plant will be sourced mainly from European die casters. The recycling plant was expected to be the forerunner of a project proposed by Antheus Magnesium BV to build a primary magnesium plant producing 50,000 t/yr of magnesium using magnesium chloride as a raw material; the primary plant was not expected until 2006 (American Metal Market, 2002b).

Hydro Magnesium, operating as Hydro Magnesium Alloys a.s., planned to continue to operate its casthouse in Porsgrunn, Norway, after the primary magnesium plant closed in April. The casthouse began operating as a remelting plant on March 18 and produced its first metal on March 20. The casthouse has a capacity of 20,000 t/yr and is operating on imported pure metal from China and returned scrap from customers in Europe (Hydro Magnesium, 2002b§). Hydro Magnesium also began operations at its new 10,000-t/yr magnesium alloy plant in Xi'an, China, in November 2001, but there were some problems with the induction furnaces. After furnace modification was completed, the plant began commercial operations in the first quarter of 2002. Hydro Magnesium expected to add a third shift in July and begin 7-day-per-week, 24-hour-per-day operations in August, at which time the plant would operate at full capacity. Metal produced at the new plant was expected to be shipped to customers in the Pacific rim (Hydro Magnesium, 2002a§).

Manganese¹⁶

Scrap recovery specifically for manganese is insignificant. To a large extent, manganese is recycled incidentally as a minor component within scrap of other metals, particularly steel and, to a much lesser degree, aluminum. High-manganese (Hadfield) steel, which has a manganese content of about 12%, is recovered for its manganese content, but the quantity of such scrap is believed to be well below 1% of the total quantity of purchased steel scrap. Recycling of aluminum and steel are discussed in the respective sections of this chapter. Manganese is ubiquitous throughout the various grades of steel, which on average contain about 0.7% manganese (Jones, 1994, p. 10). Manganese within steel scrap that is recycled to steelmaking is

largely lost because of its removal in the decarburization step of steelmaking, and needs to be added back. Manganese is recycled by the aluminum industry as a component in the scrap of certain manganese-bearing aluminum alloys, principally as UBCs in which the manganese content is about 1%. Melting and processing of aluminum is nonoxidizing toward manganese; consequently most of the manganese is retained. In 2002, the amount of manganese recycled in the aluminum industry was estimated to be slightly less than 1% of manganese apparent consumption, based on the reported weight of aluminum cans recycled (722,000 t) and the average beverage can manganese content of 0.92% (Jones, 2001§; Aluminum Association, Inc., 2002§). In the future, small additional amounts of manganese could be recovered through widespread recycling of dry-cell batteries (Watson, Andersen, and Holt, 1998).

Mercury¹⁷

The chief end use of mercury in the United States through 2000 has been as a cathode in the electrolytic production of chlorine and caustic soda from brine. These industrial chemicals are used in bulletproof glass, helmets, metal processing, paper production, pharmaceuticals, plastic production, water treatment, and a multitude of other industrial applications. Although a large amount of mercury is used in chlorine and caustic soda production, the sodium mercury amalgam is recycled within the chlorine-caustic soda plant as home or in-plant scrap with only 0.2 gram of mercury lost per metric ton of chlorine produced (Bunce and Hunt, 2003§).

Global concern for the effects of mercury on the environment and human health has caused a move towards chlorine production methods that do not use mercury. Closure of mercury-based chloralkali plants in this upcoming decade and the subsequent retirement, recycling, sale, or storage considerations for the approximately 3,000 t of mercury contained in these domestic plants is a serious concern (Raloff, 2003§).

Approximately 46 t of mercury was used by the chloralkali industry in 2001, followed by 60 t, for switches; 44 t, for dental amalgam; 28 t, for lighting; and 22 t, for measuring instruments (Bender, 2002§). Mercury in switches, amalgam, lighting, and instruments may be discarded after use, and mercury recycled from these sources is called old scrap. The toxic effects of mercury on the environment and human health necessitate that mercury used in these products be recovered before these products are incinerated or disposed of in a landfill.

Dental amalgam, introduced into the United States as a filling for decayed teeth in 1833, was originally composed of mercury and silver (Talbot, 1882). However, modern amalgam contains mercury (50%), silver (34-38%), tin (12-14%), copper (1-2%), and zinc (0-1%) (Davis, 2003§). Between 1996 and 2001, 30 to 44 t of mercury was used for dental applications. Since the 1980s, the American Dental Association (ADA) has strongly recommended use of precapsulated amalgam and recycling of all amalgam materials, including the empty amalgam capsules, as a best management practice (American Dental Association,

¹⁶Prepared by Lisa A. Corathers.

¹⁷Prepared by William E. Brooks.

2003a§). The ADA has also collaborated with metropolitan sewerage agencies and developed wastewater workshops in which mercury management and recycling options were addressed (American Dental Association, 2003b§).

In the State of Washington alone, between 1,733 and 3,356 pounds (786 and 1,522 kg) of mercury scrap must be recovered and disposed of each year from the following sources: auto switches (219 pounds or 99 kg), dental amalgam (404 pounds or 183 kg), fluorescent lamps (505 to 1,839 pounds or 229 to 834 kg), thermometers (11 to 300 pounds or 5 to 136 kg), and thermostats (444 pounds or 201 kg) (Washington Toxics Coalition, 2003§). Mercury use in batteries and paints has been discontinued in the United States. China, however, still manufactures inexpensive mercury “button” batteries that have become a health risk in some parts of the world (El Comercio, 2002§, 2003§).

Mercury used in car switches and lamps is of environmental concern during scrapping or waste treatment; however, recycled or secondary mercury can be recovered from switches, as well as batteries, dental amalgam, lamps, and mercury waste (McCann, 2002; Abernathy, 2003; Natural Resources Council of Maine, 2003§). Producers of recycled mercury include Bethlehem Apparatus Company (2003§) in Pennsylvania; D.F. Goldsmith Chemical and Metal Corporation (2003§) in Illinois; and Mercury Waste Solutions, Inc. (2003§) in Minnesota. A list of more than 50 individuals and companies that recycle mercury is available (Mercury Recyclers, 2002§).

Molybdenum¹⁸

Molybdenum is recycled as a component of catalysts, ferrous scrap (alloy and stainless steel), and superalloy scrap. Ferrous scrap consists of home, new, and old scrap. Home scrap is generated within the steel mill during production of iron and steel and is generally held captive. New scrap consists mainly of trimmings from fabrication processes, such as stampings, and recycled unusable fabricated items. New scrap also includes recycled catalysts and sludge from the production of tungsten filaments in light bulbs. Old scrap includes molybdenum-bearing alloys as well as carbon and stainless steels that are being discarded after serving their useful life in a variety of applications. The steel grades with the highest percentage of molybdenum are alloy and stainless steels; however, the highest volume of production is in carbon steel. Although molybdenum is not recovered separately from the scrap steel and superalloys that contain it, recycling of these alloys is significant, and the molybdenum content is reused. Some molybdenum content that is recycled, however, may be effectively downgraded in alloys where it is not essential. The amount of molybdenum consumed to produce new alloy and catalyst products is not recorded, but in 1998, the old scrap supply available to industry was estimated to be 26,700 t, based on the life cycles of the products in which molybdenum is used. The recycling rate, which was estimated to be 33%, is not expected to change significantly in the near term (Blossom, 2003§).

Nickel¹⁹

Austenitic stainless steel scrap is the largest source of secondary nickel for the United States, accounting for about 86% of the 99,800 t of nickel reclaimed in 2002. An additional 4% came from the recycling of alloy steel scrap. The combined 90% represents not only scrap used in raw steel production, but also lesser amounts of scrap consumed by steel and iron foundries, as well as nickel reclaimed from stainless steelmaking residues (e.g., furnace dust, grindings, and mill scale). The remaining 10% comprised copper-nickel and aluminum-nickel alloy scrap and pure nickel scrap as described below.

World demand for austenitic scrap increased substantially in 2002 because of rising prices for cut cathode and other forms of primary nickel.

In 2002, there was not enough quality 18/8 stainless steel scrap to meet global melt shop demand. This situation is not expected to change in the near future because world demand for austenitic stainless steel is estimated to grow at a rate of 3% to 6% per year (Hunter, 2002). The overall scrap ratio for the Western World was expected to remain at 45% because of the constricted supply of scrap.

Scrap availability was expected to grow along with stainless steel production. Japan and China were the largest consumers of stainless steel in 2001, followed by the United States. Blended scrap is becoming more acceptable to melt shop operators, provided that scrap quality standards are maintained and the price of the blend (plus transportation costs) is somewhat less than the delivered price of equivalent ferronickel. Payment terms also are an important consideration. The practice of blending is expected to become more widespread in order to satisfy growing melt shop demand. The evolution and improvement of the scrap collection system is the key to meeting future scrap demand. The modern scrap yard has become much more than a combined collection point and storage area. The scrap processing facility, the next step in the collection chain, also has changed significantly since the 1960s. Most of these processing facilities ship directly to the steel mills. Cleanliness of the scrap (i.e., properly segregated scrap) remains an important issue. Since the 1980s, scrap processing has become increasingly specialized. The continuing growth in stainless steel production has led to the use of larger and larger tonnages of prepared stainless steel scrap. Blended scrap is increasingly replacing the traditional Type 304 18-8 segregated scrap because of scrap generation constraints. Much of this expansion is occurring in China, India, Pakistan, and other emerging nations. In the United States and the European Union (EU), the small family-controlled scrap operation is disappearing as a result of environmental compliance costs, increased competition for available materials, and tight profit margins. Smaller niche-oriented trading companies have emerged to compete with the scrap processors (Hunter, 2002).

U.S. exports of stainless steel scrap declined to 25,700 t of contained nickel from 32,900 t in 2001, a drop of 22%. The decline in exports reflected both higher prices for primary nickel and the 39% increase in domestic austenitic production. Taiwan

¹⁸Prepared by Michael J. Magyar.

¹⁹Prepared by Peter H. Kuck.

was again the largest importing nation, purchasing 7,680 t of contained nickel in 2002. The Republic of Korea was in second place with 5,700 t and was closely followed by China, with 5,170 t.

U.S. industry recycles a broad spectrum of other nickel-bearing materials in addition to stainless steel. Copper-nickel alloy scrap and aluminum scrap accounted for about 5% of the nickel reclaimed in 2002. Scrap in this category comes from a myriad of sources and includes cupronickel (a series of copper alloys containing 2% to 45% nickel), the Monels (a group of alloys typically containing 65% nickel and 32% copper), nickel-silver (a misnomer for a series of copper-zinc-nickel alloys), and nickel-aluminum bronze. Cupronickel is stronger and more resistant to oxidation at high temperatures than pure copper, making it desirable for saltwater piping and heat exchanger tubes. Cupronickel also is widely used for coinage. Nickel-silver—a white brass—is used for camera parts, optical equipment, rivets, and screws. The aerospace industry uses several wrought aluminum alloys that contain 0.2% to 2.3% nickel.

The remaining 5% of reclaimed nickel came from pure nickel scrap and nickel-base alloy scrap. Superalloy producers and downstream fabricators of turbine engines and chemical-processing equipment generate a large part of this material, some of which is sent to scrap processors for salvaging and cleaning and later returned to the producers for remelting. Because of the stringent specifications for INCONEL 718, WASPALOY, and similar aerospace-grade superalloys, however, much of the superalloy scrap is not suitable for direct recycling and is sold to specialty alloy casting companies, stainless steel producers, or steel foundries.

Production cutbacks by the aerospace industry in 2002 resulted in even more blending, with increasing amounts of aerospace scrap being used as a nickel sweetener by scrap processors. At the same time, melt shop operators have had to pay more attention to residual elements in blended scrap.

The U.S. collection and recycling program for NiCd and nickel-metal hydride (NiMH) batteries has rapidly expanded since the passage of Federal recycling legislation in 1996. Rechargeable Battery Recycling Corporation (RBRC), a nonprofit public service corporation funded by more than 285 manufacturers and marketers of portable rechargeable batteries and battery-operated products, administers the program. The program is primarily designed to recycle the more than 75 million small, sealed, rechargeable NiCd batteries sold annually to U.S. and Canadian businesses and consumers for use in cordless products. RBRC licensees now account for four out of five NiCd sales in North America. Almost 25,000 retail outlets or community collection sites in the United States accept spent NiCd batteries. Some 4,500 collection sites in Canada also participate in the RBRC program. The bulk of the collected batteries are sent to Inmetco for reclamation.

In 2001, the European Commission drafted a directive that calls for the phaseout of cadmium in most portable batteries by January 1, 2008. The proposed directive also would establish a minimum recycling target of 55% for all collected batteries. Some 13,000 t/yr of portable NiCd batteries and 3,500 to 4,000 t/yr of industrial NiCd batteries are marketed in the EU. Industry studies show that only 11% of the portable NiCd

batteries were being reclaimed, compared with 53% of the industrial batteries (Commission of the European Communities, 2001).

Platinum-Group Metals²⁰

For most platinum-group metal (PGM) applications, the actual loss of metal during use is small, and the ability to recover the metal efficiently contributes greatly to the economics of PGM use. For the most part, spent chemical process catalysts and used equipment containing PGMs, e.g., from the glass industry, are toll refined and may not be considered as recycling. Spent automotive catalysts, however, are waste materials and continue to provide a growing secondary source of PGMs. In 2002, world recovery of platinum from spent auto catalysts was estimated to be 17,800 kg, an increase of 1,200 kg from that of 2001. In the United States, Stillwater Mining Company, Columbus, MT, reported that the company processed 1,020 t of spent auto catalysts and recovered 1,440 kg of palladium and platinum, down from 1,203 t and 2,140 kg, respectively, in 2001 (Stillwater Mining Company, 2003, p. 10-12). In addition to the PGMs recovered from spent auto catalyst, the United States imported 2,100,000 kg of platinum waste and scrap containing 77,500 kg of platinum.

In 2002, the volume of palladium recovered from scrapped catalytic converters was estimated to be 11,500 kg, an increase of 2,800 kg from 2001 recovery. Higher recovery rates were influenced by higher palladium prices in 2000 and 2001, which intensified interest in the collection of scrapped catalytic converters. Also, in the United States and Europe in particular, the average palladium content of recovered catalysts increased. Catalytic converters fitted to cars manufactured beginning in the mid-1990s contained higher loadings of palladium, and the number of these cars now being scrapped is rising.

Selenium²¹

In 2002, little secondary selenium was recovered in the United States. Used photoreceptor drums and scrap generated in the manufacture of new drums were exported for the recovery of the selenium content. Most selenium, however, is dissipated as process waste or, as in glass and metal alloys, is eventually discarded as a minor constituent of these products or volatilized during remelt.

An estimated 311 t of selenium metal, waste, and scrap was imported in 2002. It is estimated that 2002 exports of 80.9 t of selenium metal, waste, and scrap were almost double the quantity exported in 2001. This represents an increase in foreign demand for recyclable selenium materials, which is being driven by an increase in price in 2002 of more than 12% from that of 2001.

About 250 t/yr of secondary selenium is produced worldwide. This represents about 15% of refined selenium production coming from secondary sources (Selenium-Tellurium Development Association, 2002§).

²⁰Prepared by Henry E. Hilliard.

²¹Prepared by John D. Jorgenson.

One factor that during the long-term may affect the availability of selenium and stimulate additional recycling is the success of a copper concentrate leaching demonstration plant at Bagdad, AZ (Phelps Dodge Corporation, 2003). This plant's concentrate pressure leach with solvent extraction and electrowinning (SX/EW) technology represents a less expensive alternative to conventional smelting and refining for chalcopyrite flotation concentrates. Copper recovery for this new process has averaged 98%, but since it is an electrowinning process, selenium-rich anode slimes may not be produced. The recovery of byproducts from the new process technology is currently under evaluation.

Silver²²

About 1,030 t of silver valued at \$152 million was recovered from scrap in 2002, about 3% less than that of 2001. Photographic scrap was estimated to have generated about 1,000 t of silver, the largest part was recovered from spent fixer solution and x-ray and graphic arts wastes, and a small quantity, directly from color film wastes. The remainder was recovered from electronic scrap, jewelers' sweepings, spent catalysts, and other heterogeneous silver bearing materials. The small increase in silver recycling in the United States can be attributed mainly to the fact that scrap supply has declined, showing little response to the price increase within the price range in which silver was traded during 2002. A price almost double the 2002 average of \$4.62 per ounce would be required to induce a significant surge in the volume of scrap. Also, conservation and substitution (product miniaturization/lower loadings and substitution of nonprecious metals) reduced silver scrap supply significantly in 2002. However, this was somewhat offset by tighter environmental regulations and the decommissioning of at least one ethylene oxide plant. Silver is used as a catalyst in the production of ethylene oxide, and the closure made the catalyst available for recycling. Scrap supplies from silver halide photography have yet to show a decline in response to inroads of digital photography.

Tantalum²³

Tantalum is ductile, easily fabricated, a good conductor of heat and electricity, highly resistant to corrosion by acids, and has a high melting point. The major use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. More than 60% of total tantalum consumed is in the electronics industry. Major end uses for tantalum capacitors include automotive electronics, pagers, personal computers, and portable telephones. Alloyed with other metals, tantalum is also used in making carbide tools for metalworking equipment and in the production of superalloys for aircraft engine components. Such substitutes as aluminum, rhenium, titanium, tungsten, and zirconium can be used in place of tantalum but are usually used at either a performance or economic penalty.

In 2002, U.S. apparent consumption of all tantalum materials decreased to about 500 t from about 550 t owing to excess tantalum inventories and the depressed state of the electronics industry; consumed scrap (from various sources) accounted for an estimated 20% of the total. Tantalum was mostly recycled from new scrap that was generated during the manufacture of tantalum-containing electronic equipment and from new and old scrap products of tantalum-containing cemented carbides and superalloys. The amount of tantalum recycled from finished electronic components (old scrap), however, is very small because this source has not yet been fully developed. New scrap materials reclaimed at manufacturing plants that produce tantalum-containing electronic equipment are a major source of tantalum supply and are delivered back to tantalum processors for recycling (Cunningham, 2003c§).

Tin²⁴

In 2002, 20% of the domestic apparent supply of tin metal was recovered from scrap (table 1). Old tin scrap is collected at hundreds of domestic scrap yards, three detinning plants, and most municipal collection-recycling centers. New tin scrap is generated mainly in the tin mills of six steel plants, scores of can making facilities, numerous brass and bronze plants, and many solder-making operations.

Detinning facilities are unique to the tin scrap industry in that no other major metal industry has numerous large-scale plants to remove plated metal. Detinning operations are performed on new tinplate scrap from tin mills or can-making plants and on old tinplate scrap in the form of used tin cans. For most of the past century, the detinning process has been the only technique in the secondary tin industry by which free tin metal returns to the marketplace. The bulk of the secondary tin industry works with the various alloy forms of tin (brass, bronze, solder, etc.); the tin is recycled within its own product-line industries, and this tin reappears in regenerated alloys.

The Steel Recycling Institute (SRI), a business unit of the American Iron and Steel Institute, continued to promote the recycling of used tin cans, which has been an important raw material for the Nation's steel industry during the past 20 years. The SRI announced that the domestic steel can recycling rate had increased slightly in 2002 to 59% compared with 58% in 2001, 56% in 1995, and 15% in 1988 (Steel Recycling Institute, 2003).

Tin scrap prices are rarely published but generally approximate the prices for primary tin metal.

Titanium²⁵

The production of titanium components generates significant quantities of new scrap. New scrap is generated during the melting, forging, casting, and fabrication of titanium components, while old scrap is recovered from used components (old aircraft parts, heat exchangers, etc.).

Titanium scrap is sought as an alternative to titanium sponge and alloying materials in the production of titanium ingot.

²²Prepared by Henry E. Hilliard.

²³Prepared by Larry D. Cunningham

²⁴Prepared by James F. Carlin, Jr.

²⁵Prepared by Joseph Gambogi.

Scrap is recycled into titanium ingot either with or without virgin metal using traditional vacuum-arc-reduction and cold-hearth melting practices. In the United States, titanium ingot producers (recyclers) included Allegheny Technologies Inc., Howmet Corp., Lawrence Aviation Industries Inc., RMI Titanium Co., and Titanium Metals Corp. Numerous companies were involved in the generation, segregation, and processing of scrap for recycling.

Sluggish production of commercial aircraft frames and engines caused U.S. consumption of scrap for the production of titanium ingot to decrease by 32% in 2002 compared with that of 2001. Compared with sponge, scrap supplied about 40% of the titanium required for ingot production. Although no data are available as to the percentage breakdown of sources of titanium scrap, it is estimated that less than 5% of titanium ingot production is derived from old scrap.

Titanium scrap also is consumed by the steel and nonferrous alloy industries. Titanium is used in steelmaking for deoxidation, grain-size control, and carbon and nitrogen control and stabilization. Titanium is introduced during steelmaking as a ladle addition often in the form of ferrotitanium because of its lower melting point and higher density when compared with titanium scrap. Ferrotitanium is produced from titanium and steel scrap by induction melting. World ferrotitanium production capacity is led by, in descending capacity order, the United Kingdom, Russia, Japan, and the United States. In 2002, there were three domestic producers of ferrotitanium—Global Titanium, Inc., Detroit MI; Galt Alloys Inc., North Canton, OH; and ShieldAlloy Inc., Newfield, NJ. In addition to domestic producers, several companies were involved in the trade of ferrotitanium. Consumption by the steel industry is largely associated with the production of stainless steels. In the nonferrous metals industry, titanium scrap is primarily consumed to produce aluminum-titanium master alloys for the aluminum industry. When used in aluminum alloys, titanium improves casting and reduces cracking.

Imports and exports of titanium scrap include material to be recycled back into titanium components as well as that consumed by steel and nonferrous alloys. In 2002, imports and exports of titanium scrap were evenly matched, with imports exceeding exports by only 265 t. Imports and exports of titanium scrap decreased 46% and 20%, respectively, compared with those of 2001.

Owing to a drop in available supply, the published price range for unprocessed titanium scrap turnings increased to between \$1.07 and \$1.10 per pound at yearend 2002 from between \$0.68 and \$0.70 per pound at yearend 2001. Yearend prices for ferrotitanium also increased to between \$2.16 and \$2.18 per pound in 2002 from between \$1.60 and \$1.70 per pound in 2001.

Future consumption of titanium scrap is largely dependent on demand for titanium metal products by the aerospace industry. Although the long-term growth in titanium demand is expected to exceed 5%, titanium demand by the aerospace industry is highly cyclical. Growth in the consumption of ultra-low-carbon steels for automotive applications and appliances is expected to increase demand for ferrotitanium. Given the long-term growth trend for ferrotitanium imports, imports are expected to meet much of the future domestic demand for ferrotitanium.

Tungsten²⁶

In 2002, an estimated 25% to 30% of world tungsten supply was from recycled materials (Maby, 2002, p. 5). Tungsten-bearing scrap originates during manufacture and/or after use in the following applications: alloys, such as tool steels, high-speed steels, and superalloys; cemented carbides used for cutting and wear-resistant applications; and mill products made from metal powder, such as filaments and electrodes for lamps and heavy metal alloys. Depending on the type and quality of the scrap, it can be recycled by the industry sector that generated it, used as a source of tungsten by another consuming industry, or used as a substitute for tungsten concentrate by tungsten processors (Smith, 1994, p. 4-14).

Several processes recycle cemented carbide scrap. Some of them result in tungsten carbide powder mixed with cobalt, which can be used to make new cemented carbide parts. In other processes, the cobalt is recovered separately, and the tungsten is converted to the intermediate product ammonium paratungstate from which tungsten carbide powder, chemicals, or metal powder can be produced. Tungsten metal scrap from the manufacture of mill products is used to make cast carbides, ferrotungsten, superalloys, and tool steel. It can also be processed chemically to produce ammonium paratungstate. Most heavy-metal-alloy-manufacturing scrap is recycled as home scrap to a prealloyed powder, but it can also be chemically converted to ammonium paratungstate or used to produce tool steel (Kieffer, 1982, p. 102-107). Steel scrap and superalloy scrap are recycled by the steel and superalloys industries, respectively.

In 2002, scrap consumption reported by U.S. tungsten processors and consumers contained 4,380 t of tungsten, a decrease of 19% from 5,390 t in 2001. The United States imported 903 t of tungsten contained in waste and scrap (valued at \$5.4 million), 16% less than the tungsten content of waste and scrap imports in 2001. Seven countries supplied most of these imports—China, 28%; Germany, 16%; Japan, 12%; the United Kingdom, 10%; and Hong Kong, Pakistan, and South Africa, 6% each. U.S. exports of tungsten waste and scrap totaled an estimated 353 t of contained tungsten valued at \$2.6 million. The leading destinations for these exports were the United Kingdom, 33%; China, 17%; Hong Kong, 14%; Germany, 13%; Belgium and Netherlands, 6% each; and Taiwan, 5%. Exports of tungsten waste and scrap in 2001 were not reported separately from those of unwrought tungsten.

Vanadium²⁷

The principal use of vanadium is as an alloying element. Very small quantities of vanadium, often less than 1%, are alloyed with other metals to produce various ferrous and nonferrous alloys. Owing to the relatively small amount of vanadium involved, these alloys in general do not lend themselves to recycling for vanadium recovery. Vanadium is also used as a catalyst. It is estimated that catalyst consumption accounts

²⁶Prepared by Kim B. Shedd.

²⁷Prepared by Michael J. Magyar.

for less than 1% of the total U.S. vanadium consumption. Processing spent vanadium catalysts, however, accounts for the only significant source of refined secondary vanadium. Three plants in Arkansas, Louisiana, and Texas accounted for most of the recycled vanadium catalyst. Any new scrap generated in either the production of alloys or catalysts is likely reused internally.

Zinc²⁸

In 2002, about 30% of world zinc production was from secondary materials—brass, die casting scrap, flue dust, galvanizing residues, zinc sheet, etc. In the United States, more than one-fourth of the 1.2 Mt consumed by domestic industries was secondary zinc. About 87% of recycled zinc was derived from new scrap, generated mainly in galvanizing and die casting plants and brass mills. The remaining 13% was obtained from brass products, flue dust, old die casts, and old rolled zinc articles. Recycled zinc was used by 2 primary smelters and 13 large-and-medium (more than 1,000 t/yr)-sized secondary smelters principally for production of zinc chemicals, mainly oxide, and zinc metal, including alloys. In addition, there is a changing number of smaller companies that usually produce pure zinc chemicals. IMCO Recycling Inc., Midwest Zinc Corp., and Zinc Corporation of America are the largest users of secondary zinc.

Because of wide differences in the character and zinc content of scrap, the recycling processes of zinc-bearing scrap vary widely. Clean new scrap, mainly brass, rolled zinc clippings, and rejected die castings, usually requires only remelting. In the case of mixed nonferrous shredded metal scrap, zinc is separated from other materials by hand or magnetically. Most of the zinc recovered from EAF dust produced during remelting of galvanized steel scrap is recovered in rotary kilns by using the Waelz process. Because the most common use of zinc is for galvanizing, the latest research is aimed mainly at stripping zinc from galvanized steel scrap before remelting.

In 2002, trade in zinc scrap was small—about 3% of total domestic consumption. About 93% of imported zinc scrap was supplied by Canada, and the major destination of U.S. exports was India (36%), followed by China (35%) and Taiwan (12%).

Prices for scrap varied according to environmental difficulties in handling, transporting, or treating, geographic location, presence of other components, and quality. The price for a ton of zinc metal contained in scrap was about three-fourths of the LME price for refined zinc metal.

Zirconium²⁹

Zirconium scrap comprises about 30% to 35% of the feedstock for ingot production. New scrap is generated during the melting, forging, rolling, casting, and fabrication of zirconium components. In addition, small quantities of obsolete or old scrap are recycled from dismantled process equipment, heat exchangers, vessels, etc. Although no data are available as to the percentage

breakdown of scrap sources, it is estimated that less than 2% of ingot production is derived from old scrap. Prior to melting, scrap must be analyzed, classified, and processed to remove impurities. Several companies have proprietary processes to accomplish this task. Scrap is initially melted without virgin metal by two domestic ingot producers—Wah Chang (a subsidiary of Allegheny Technologies Inc., Albany, OR) and Western Zirconium (a subsidiary of Westinghouse Electric Company, Ogden, UT)—using vacuum-arc-reduction melting practices.

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²⁹Prepared by James B. Hedrick.

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GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

- Mineral Commodity Summaries, annual.
- Mineral Industry Surveys, monthly.

TABLE 1
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS¹

Year	Quantity of metal (metric tons)					Value of metal (thousands)			
	Recycled from new scrap ²	Recycled from old scrap ³	Recycled ⁴	Apparent supply ⁵	Percentage recycled	Recycled from new scrap ²	Recycled from old scrap ³	Recycled ⁴	Apparent supply ⁶
Aluminum: ⁷									
1998	1,950,000	1,500,000	3,440,000	9,040,000	38	\$2,810,000	\$2,160,000	\$4,970,000	\$13,100,000
1999	2,120,000	1,570,000	3,700,000	9,890,000	37	3,070,000	2,280,000	5,350,000	14,300,000
2000	2,080,000	1,370,000	3,450,000	9,610,000	36	3,420,000	2,260,000	5,670,000	15,800,000
2001	1,760,000 ^r	1,210,000	2,970,000 ^r	7,990,000 ^r	37	2,670,000 ^r	1,830,000 ^r	4,500,000 ^r	12,100,000
2002	1,750,000	1,170,000	2,930,000	8,060,000	36	2,510,000	1,680,000	4,190,000	11,500,000
Chromium: ⁸									
1998	NA	NA	104,000	524,000	20	NA	NA	91,500	551,000
1999	NA	NA	118,000	558,000	21	NA	NA	77,700	387,000 ^r
2000	NA	NA	139,000	589,000	24	NA	NA	98,600	414,000 ^r
2001	NA	NA	122,000	326,000 ^r	38 ^r	NA	NA	70,900 ^r	249,000 ^r
2002	NA	NA	139,000	482,000	29	NA	NA	75,700	298,000
Copper: ⁹									
1998	956,000	466,000	1,420,000	3,980,000	35.7	1,660,000	808,000	2,470,000	6,900,000
1999	949,000	381,000	1,330,000	4,080,000	32.5	1,590,000	637,000	2,220,000	6,820,000
2000	955,000	357,000	1,310,000	4,080,000	32.1	1,860,000	693,000	2,550,000	7,930,000
2001	833,000	316,000	1,150,000	3,330,000 ^r	34.5	1,410,000	535,000	1,950,000	5,640,000 ^r
2002	842,000	207,000	1,050,000	3,450,000	30.4	1,410,000	346,000	1,750,000	5,770,000
Iron and steel: ¹⁰									
1998	NA	NA	73,000,000	133,000,000	55	NA	NA	7,910,000	17,400,000
1999	NA	NA	71,000,000	130,000,000	55	NA	NA	6,680,000	12,300,000
2000	NA	NA	74,000,000	134,000,000	55	NA	NA	7,100,000	12,800,000
2001	NA	NA	71,000,000	118,000,000 ^r	60	NA	NA	5,320,000	8,880,000
2002	NA	NA	69,000,000	119,000,000	58	NA	NA	6,390,000	10,200,000
Lead: ¹¹									
1998	45,800	1,050,000	1,100,000	1,740,000	63.1	45,700	1,050,000	1,100,000	1,740,000
1999	42,700	1,050,000	1,090,000	1,790,000	60.9	41,200	1,010,000	1,050,000	1,730,000
2000	35,500	1,080,000	1,120,000	1,790,000	62.6	34,100	1,040,000	1,080,000	1,720,000
2001	47,300	1,040,000 ^r	1,090,000 ^r	1,700,000	64.1 ^r	45,500	1,000,000 ^r	1,050,000 ^r	1,640,000
2002	34,800	1,070,000	1,100,000	1,540,000	71.4	33,400	1,030,000	1,060,000	1,480,000
Magnesium: ¹²									
1998	45,200	31,800	77,100	226,000	34	158,000	111,000	284,000	788,000
1999	52,000	34,200	86,100	231,000	37	178,000	117,000	294,000	789,000
2000	52,200	30,100	82,300	209,000	39	158,000	90,800	248,000	630,000
2001	38,600	27,200	65,800	162,000	41	106,000	75,000	181,000	446,000
2002	47,100	26,400	73,600	162,000	45	126,000	70,500	196,000	432,000
Nickel: ¹³									
1998	NA	NA	63,100	212,000	30	NA	NA	292,000	983,000
1999	NA	NA	71,000	211,000	34	NA	NA	427,000	1,270,000
2000	NA	NA	84,000	231,000 ^r	36	NA	NA	725,000 ^r	2,000,000
2001	NA	NA	101,000	230,000 ^r	44	NA	NA	600,000	1,370,000
2002	NA	NA	99,800	221,000	45	NA	NA	676,000	1,500,000
Tin: ¹⁴									
1998	8,470	7,790	16,300	54,600	30	69,600	64,000	134,000	449,000
1999	8,650	7,720	16,400	57,300	29	70,400	62,800	133,000	466,000
2000	9,140	6,560	15,700	54,500	29	74,400	53,500	128,000	443,000
2001	7,210 ^r	6,700	13,900	46,300 ^r	30 ^r	50,000 ^r	46,500	96,400 ^r	321,000 ^r
2002	3,590	6,410	10,000	51,200	20	23,100	41,200	64,200	329,000
Titanium: ¹⁵									
1998	NA	NA	28,600	W	50	NA	NA	22,100 ^e	NA
1999	NA	NA	21,900	W	55	NA	NA	28,900 ^e	NA
2000	NA	NA	18,500	W	50	NA	NA	38,200 ^e	NA
2001	NA	NA	17,000	W	39	NA	NA	35,200 ^e	NA
2002	NA	NA	11,600	W	40	NA	NA	25,600 ^e	NA

See footnotes at end of table.

TABLE 1--Continued
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS¹

Year	Quantity of metal (metric tons)					Value of metal (thousands)			
	Recycled from new scrap ²	Recycled from old scrap ³	Recycled ⁴	Apparent supply ⁵	Percentage recycled	Recycled from new scrap ²	Recycled from old scrap ³	Recycled ⁴	Apparent supply ⁶
Zinc: ¹⁶									
1998	344,000	89,900	434,000	1,580,000	27.5	\$352,000	\$92,100	\$444,000	\$1,620,000
1999	321,000	78,100	399,000	1,610,000	24.8	379,000	92,200	471,000	1,900,000
2000	369,000	70,300	439,000	1,630,000	26.9	454,000	90,000	544,000	2,020,000
2001 [†]	317,000	57,000	375,000	1,410,000	26.6	307,000	55,200	362,000	1,370,000
2002	319,000	47,300	366,000	1,430,000	25.6	272,000	40,300	312,000	1,220,000

[†]Estimated. [†]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Scrap that results from the manufacturing process, including metal and alloy production. New scrap of aluminum, copper, lead, tin, and zinc excludes home scrap. Home scrap is scrap generated and recycled in the metal producing plant.

³Scrap that results from consumer products.

⁴Metal recovered from new plus old scrap.

⁵Apparent supply is production plus net imports plus stock changes. Production is primary production plus recycled metal. Net imports are imports minus exports. Apparent supply is calculated on a contained weight basis.

⁶Same as apparent supply defined in footnote 5 above but calculated based on a monetary value.

⁷Quantity of metal is the calculated metallic recovery from purchased new and old aluminum-base scrap, estimated for full industry coverage. Monetary value is estimated based on average U.S. market price for primary aluminum metal ingot.

⁸Chromium scrap includes estimated chromium content of stainless steel scrap receipts (reported by the iron and steel and pig iron industries) where chromium content was estimated to be 17%. Trade includes reported or estimated chromium content of chromite ore, ferrochromium, chromium metal and scrap, and a variety of chromium-containing chemicals. Stocks include estimated chromium content of reported and estimated producer, consumer, and Government stocks. Recycled value calculated from quantity using the average annual import value of high-carbon ferrochromium. Apparent supply value calculated from quantity using average annual trade value.

⁹Includes copper recovered from unalloyed and alloyed copper-base scrap, as refined copper or in alloy forms, as well as copper recovered from aluminum-, nickel-, and zinc-base scrap. Monetary value based on annual average refined copper prices.

¹⁰Iron production measured as shipments of iron and steel products plus castings corrected for imported ingots and blooms. Secondary production measured as reported consumption. Apparent supply includes production of raw steel. Monetary value based on U.S. annual average composite price for No. 1 heavy melting steel calculated from prices published in American Metal Market.

¹¹Lead processors are segregated by primary and secondary producers. This segregation permits inclusion of stock changes for secondary producers. Monetary value of scrap and apparent supply estimated based upon average quoted price of common lead. Excludes copper-based scrap.

¹²Includes magnesium content of aluminum-base scrap. Monetary value based on the annual average Platts Metals Week's U.S. spot Western price.

¹³Nickel statistics were derived from the following:

Canvass data

- Reported nickel content of products made from reclaimed stainless steel dust, spent nickel-cadmium batteries, plating solutions, etc.
- Estimated nickel content of reported net receipts of alloy and stainless steel scrap.
- Reported nickel content of recovered copper-base scrap.
- Reported nickel content of obsolete and prompt purchased nickel-base scrap.
- Estimated nickel content of various types of reported obsolete and prompt aluminum scrap.

Trade data

- Reported nickel content of International Nickel Study Group (INSG) class I primary products, including cathode, pellets, briquets, powder, and flake.
- Reported or estimated nickel content of INSG class II primary products, including ferronickel, metallurgical-grade nickel oxide, and a variety of nickel-containing chemicals.
- Estimated nickel content of secondary products, including nickel waste and scrap and stainless steel scrap.

Stock data

- Reported or estimated nickel content of all scrap stocks, except copper.
- Reported nickel content of primary products held by world producers in U.S. warehouses.
- Reported nickel content of primary products held by U.S. consumers.
- Reported nickel content of U.S. Government stocks.

Monetary value based on annual average cash price for cathode, as reported by the London Metal Exchange.

¹⁴Monetary value based on Platts Metals Week composite price for tin.

¹⁵Percentage recycled based on titanium scrap consumed divided by primary sponge and scrap consumption.

¹⁶Monetary value based on annual average Platts Metal Week metal price for North American special high-grade zinc.

TABLE 2
SALIENT U.S. RECYCLING TRADE STATISTICS FOR SELECTED METALS¹

Year	Exports			Imports for consumption		
	Quantity		Value (thousands)	Quantity		Value (thousands)
	Gross weight (metric tons)	Contained weight (metric tons)		Gross weight (metric tons)	Contained weight (metric tons)	
Aluminum:						
1998	428,000	NA	\$453,000	501,000	NA	\$572,000
1999	419,000	NA	445,000	615,000	NA	666,000
2000	576,000	NA	648,000	625,000	NA	744,000
2001	580,000	NA	588,000	497,000	NA	552,000
2002	613,000	NA	603,000	466,000	NA	502,000
Chromium:²						
1998	298,000	50,700	176,000	57,200	9,720	21,600
1999	260,000	44,100	151,000	66,200	11,300	27,800
2000	468,000	79,600	310,000	56,200	9,600	36,100
2001	438,000	74,500	270,000	42,400	7,240	24,200
2002	343,000	58,300	252,000	81,100	13,900	50,600
Copper:³						
1998	307,000	239,000	401,000	166,000	135,000	234,000
1999	315,000	250,000	366,000	136,000	108,000	167,000
2000	485,000	395,000	537,000	144,000	112,000	186,000
2001	534,000	439,000	538,000	115,000	91,100	144,000
2002	511,000	407,000	509,000	100,000	80,300	128,000
Iron and steel:						
1998	5,950,000	5,950,000	820,000	3,370,000	3,370,000	448,000
1999	5,560,000	5,560,000	755,000	4,020,000	4,020,000	427,000
2000	5,810,000	5,810,000	1,020,000	3,630,000	3,630,000	419,000
2001	7,530,000	7,530,000	1,150,000	2,810,000	2,810,000	298,000
2002	9,000,000	9,000,000	1,300,000	3,320,000	3,320,000	403,000
Lead:						
1998	99,200	99,200	19,900	6,880	5,710	3,550
1999	117,000	117,000	22,000	13,200	10,900	6,100
2000	71,600	71,600	13,200	13,400	12,100	5,140
2001	108,000	108,000	24,900	10,700	10,200	4,260
2002	106,000	106,000	23,300	2,880	2,570	1,740
Magnesium:						
1998	13,200	13,200	30,100	5,720	5,720	7,910
1999	16,500	16,500	46,500	6,780	6,780	7,690
2000	6,400	6,400	17,500	9,890	9,890	16,400
2001	6,950	6,950	18,600	11,000	11,000	19,200
2002	5,850	5,850	14,700	14,100	14,100	20,900
Nickel:⁴						
1998	1,060,000	38,000	346,000	349,000	9,630	93,600
1999	842,000	33,700	306,000	285,000	10,300	84,500
2000	1,310,000	53,100	538,000	446,000	12,300	137,000
2001	1,070,000	51,000	533,000	252,000	9,550	95,000
2002	1,070,000	42,200	506,000	358,000	10,200	107,000
Tin:						
1998	9,360	9,360	8,330	4,190	4,190	2,480
1999	8,610	8,610	8,800	2,730	2,730	2,530
2000	5,910	5,910	5,290	2,340	2,340	4,460
2001	3,230	3,230	4,640	3,700	3,700	1,860
2002	5,940	5,940	9,740	561	561	736
Titanium:						
1998	7,010	NA	14,100	9,770	NA	34,600
1999	8,130	NA	11,700	6,870	NA	19,500
2000	5,060	NA	12,700	7,550	NA	24,100
2001	7,500	NA	18,300	11,600	NA	41,200
2002	6,000	NA	14,200	6,270	NA	17,800

See footnotes at end of table.

TABLE 2--Continued
 SALIENT U.S. RECYCLING TRADE STATISTICS FOR SELECTED METALS¹

Year	Exports			Imports for consumption		
	Quantity		Value (thousands)	Quantity		Value (thousands)
	Gross weight (metric tons)	Contained weight (metric tons)		Gross weight (metric tons)	Contained weight (metric tons)	
<u>Zinc:</u>						
1998	35,000	NA	\$27,500	29,200	NA	\$15,700
1999	28,200	NA	24,400	26,600	NA	13,100
2000	36,100	NA	21,600	26,500	NA	16,200
2001	44,000	NA	22,800	39,300	NA	11,600
2002	47,700	NA	23,000	31,200	NA	9,530

NA Not available.

¹Contained weight based upon 100% of gross, unless otherwise specified.

²Contained weight for import and export quantities of Harmonized Tariff Schedule of the United States (HTS) code 7204.21.000 is 17% of gross weight.

³For HTS codes 7404.00.0045, 7404.00.0062, 7404.00.0080, contained weight for import quantity is 65% of gross weight. For HTS codes 7404.00.3045, 7404.00.3055, 7404.00.3065, 7404.00.3090, 7404.00.6045, 7404.00.6055, 7404.00.65, and 7404.00.6090 contained weight for import quantity is 72%.

⁴Contained weight for import and export quantities is 0.4% of gross weight for HTS code 7204.29.000, 50% for 7503.00.00, and 7.5% for HTS code 7204.21.0000.