Recycling—Metals

By Staff

Introduction[1]

Metals are important, reusable resources. Although the ultimate supply of metal is fixed by nature, human ingenuity determines the quantity of supply available for use by developing economic processes for the recovery from the Earth (the primary source of metal) and from secondary sources (recycled 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, such as energy savings, reduced volumes of waste, and reduced emissions associated with energy savings.

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, volume I, Metals and Minerals.

The term “primary” indicates material from ore deposits, and the term “secondary” indicates material from recycled material, 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.” “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, or sheets—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 cuttings, stampings, turnings, 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 appliances, automobiles, and beverage cans (UBCs) 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 external scrap, home scrap, internal scrap, mill scrap, prompt scrap, and purchased scrap, have evolved to describe scrap generated by diverse industry practices. The material flow of recycled metal commodities in the United States has been documented in a series of reports published by the USGS (Sibley, 2004).

Aluminum[2]

Aluminum recovered from purchased scrap increased to 3.03 million metric tons (Mt). Of this recovered metal, about 60% came from new (manufacturing) scrap, and 40% came from old (discarded aluminum products) scrap. Aluminum UBCs accounted for about 58% of the reported old scrap consumption in 2004. According to figures released by the Aluminum Association Inc., the Can Manufacturers Institute, and the Institute of Scrap Recycling Industries, Inc., 51.5 billion aluminum UBCs were recycled in the United States in 2004, for a beverage can recycling rate of 51.2%. This reflected a 1.2% increase above the 2003 rate and the first increase since 1997 (Aluminum Association Inc., 2005).

Purchase prices for aluminum scrap, as quoted by American Metal Market, fluctuated during the year but closed at slightly higher levels than those at the beginning of the year. The 2004 yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 61 to 62 cents per pound; old sheet and cast aluminum, 56 to 58 cents per pound; and clean, dry aluminum turnings, 54 to 55 cents per pound.

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 53.5 to 55.0 cents per pound and closed the year at 63 to 65 cents per pound. The annual average American Metal Market price for aluminum UBCs increased to 61.0 cents per pound in 2004 from 50.5 cents per pound in 2003.

The yearend indicator prices for selected secondary aluminum ingots, as published in American Metal Market, increased compared with those at the beginning of the year. The closing prices for 2004 were as follows: alloy A380 (3% zinc content), 87.5 cents per pound; alloy B380 (1% zinc content), 90.2 cents per pound; alloy A360 (0.6% copper content), 94.0 cents per pound; alloy A413 (0.6% copper content), 93.9 cents per pound; and alloy 319, 92.6 cents per pound. Platts Metals Week published an annual average U.S. price of 82.3 cents per pound for A380 alloy (3% zinc content). The annual average London Metal Exchange Ltd. (LME) cash price for a similar A380 alloy was 70.7 cents per pound, and the annual average LME North American Special Aluminium Alloy Contract cash price was 74.4 cents per pound.

Beryllium[3]

Most U.S. beryllium consumption was in the form of beryllium-copper alloys, the main uses of which are electrical and electronic components. Only a small amount of beryllium 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 0.2% to 2.7% beryllium. Little beryllium

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[3]Prepared by Kim B. Shedd.

metal old scrap was recycled, because 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, so 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 represent as much as 10% of U.S. beryllium apparent consumption (Cunningham, 2004§[4]; Copper Development Association, undated§).

In 2004, the United States imported 17.2 metric tons (t), gross weight, of beryllium waste and scrap valued at $51,000 from Singapore (99%) and Germany (1%). The United States exported 1.5 t, gross weight, of beryllium waste and scrap valued at $51,000 to China (55%), the United Kingdom (34%), Italy (8%), and Finland (3%).

Cadmium[5]

In 2004, secondary production in the United States amounted to about 400 t of metal. International Metals Reclamation Co., Inc. (Inmetco) operated the only cadmium recycling facility in the country. The bulk of the cadmium came from spent nickel-cadmium (NiCd) batteries. The cadmium facility, in Ellwood City, PA, is part of a much larger nickel-chromium recovery complex that accepts a broad spectrum of waste products. Inmetco was set up in 1978 to process electric arc furnace dusts, mill scale, and swarf from stainless steel plants. Since then, its feedstock has been broadened to include nickel and chromium plating solutions, sludges, and filter cakes in addition to spent nickel-base batteries.

The U.S. collection and recycling program for NiCd and nickel-metal hydride (NiMH) batteries has expanded rapidly since the passage of Federal recycling legislation in 1996. The Rechargeable Battery Recycling Corporation (RBRC), a nonprofit public service organization, administers the program. The organization also promotes the recycling of lithium-ion and small sealed lead rechargeable batteries. The bulk of the NiCd and NiMH batteries are sent to Inmetco for reclamation. Seven of the 50 States have laws requiring the proper disposal and recycling of NiCd and small sealed lead batteries. Rechargeable batteries are commonly found in camcorders, cellular and cordless phones, cordless power tools, digital cameras, laptop computers, remote control toys, and two-way radios. In 2004, RBRC established an all-in-one cell phone and battery collection system for Canada and the United States. In Canada, 68% of all households now have one or more cell phones.

The first cadmium distillation furnace was brought online in December 1995, with the facility becoming fully operational in April 1996. Electric utilities, military bases, railroads, and telecommunications companies ship a variety of large vented and industrial batteries to Inmetco for metals recovery. These spent batteries—used primarily for backup power—arrive in the Department of Transportation-approved 55-gallon drums, in plastic tote containers, or on pallets and are segregated shortly afterwards by battery chemistries. The large NiCd batteries, usually weighing more than 2 kilograms (kg) and containing an average of 15% cadmium, are emptied of their caustic electrolyte and dismantled. The detached cadmium plates then go directly into the furnace, where the cadmium is recovered by distillation. Inmetco also accepts small consumer cells that are used in cellular telephones, cordless power tools, and household appliances. These smaller NiCd batteries are first roasted in a large vacuum oven to burn off their plastic casings and electrode separators. The nickel-cadmium-rich residue is then cooled and transferred from the oven to one of the cadmium distillation furnaces. The final product—pellets of 99.95% pure cadmium metal—is shipped to battery manufacturers for reuse. The pellets are also used in pigments (Hanewald, Schweers, and Liotta, 1996).

Most of the NiCd batteries collected in Canada go to Inmetco. The European Union (EU) and Japan have at least eight major NiCd battery recycling facilities. SAFT NIFE, Inc. of Valdosta, GA, operates a consolidation center in the United States for spent rechargeable batteries. SAFT NIFE ships its NiCd batteries to a sister facility in Oskarshamn, Sweden. Both operations are subsidiaries of Alcad Limited, a European-base rechargeable battery manufacturer. The United Kingdom has no facilities for recycling NiCd batteries and ships the bulk of its spent NiCd batteries to France for recycling by Sté. Nouvelle d'Affinage des Métaux S.A.R.L. (SNAM). SNAM has two plants—one at Viviez (Aveyron) in the Massif Central region and another at St. Quentin Fallavier (Isere) near Lyon. Part of SNAM's output goes to Floridienne Chimie S.A. of Belgium, where the metal is converted into cadmium oxide. Floridienne Chimie and SNAM are both members of the F.W. Hempel Group. The Viviez plant can treat 4,000 metric tons per year (t/yr) of cadmium containing waste; the St. Quentin Fallavier plant, 1,400 t/yr (David, 1995; Sté. Nouvelle d'Affinage des Métaux S.A.R.L., 1999§). Collection centers in New South Wales, Australia, have been shipping spent batteries to both Oskarshamn and Viviez.

Chromium[6]

The major end use of chromium is in stainless steel, and this is the major form in which chromium is recycled. Stainless steel scrap can be a substantial fraction of the starting materials from which stainless steel is produced. Stainless steel is composed of two broad categories—austenitic and ferritic. The names are related to the molecular structure of the steel and 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

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

[5]Prepared by Peter H. Kuck.

[6]Prepared by John F. Papp.

scrap). Scrap from these sources is collected and sorted by grade in scrap yards. Scrap brokers, collectors, and yards 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 production mass-weighted 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, 2004).

Nickel is a factor in the cost of stainless steel. About three-quarters of stainless steel produced requires nickel; all stainless steel requires chromium. From a general and simple point of view, stainless steel is characterized by its crystal structure, chemical composition, and microscopic structure. In crystal structure, stainless steel is classified as austenitic (a face-center cubic crystal structure) or ferritic (which has a body-center cubic crystal structure). The American Iron and Steel Institute (AISI) categorizes stainless steels by chemical composition into "types"; however, a variety of other systems are used domestically and worldwide. For example, Type 200, Type 300, Type 400, and Type 500 are AISI categories where the "00" may be replaced by other digits to indicate variation in chemical content and, therefore, material properties. Type 200 and Type 300 are austenitic stainless steels; Type 400 and Type 500 are ferritic. Nickel promotes the austenitic structure, and all austenitic grades contain nickel. While they do not require nickel, some ferritic grades permit nickel. Austenitic grades are generally recognized to be more easily fabricated, more corrosion resistant, stronger, and to perform better under extreme conditions; however, ferritic grades perform satisfactorily and are more economic to use in many applications. As the nickel price has risen to historically high levels, the cost difference between nickel-containing and nickel-free stainless steel has increased encouraging the use of nickel-free or reduced-nickel grades. Depending upon fabrication and application requirements, two nickel-reducing options are available to austenitic stainless steel users; switch to a reduced-nickel austenitic stainless or to a ferritic grade. Type 200 stainless steels are a reduced-nickel-containing austenitic grade that contains about one-half of the nickel contained in typical Type 300 series austenitic stainless steels. Type 200 stainless steels compensate for the reduced nickel with manganese and nitrogen. Since stainless steel-production-driven demand for nickel is growing faster than nickel supply, it appears inevitable that the fraction of nickel-containing stainless steel production will shrink, requiring changes in melting and scrap handling practice.

Cobalt[7]

Cobalt-bearing scrap is generated during manufacture and/or after 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, 2004, p. M5-M12).

In 2004, scrap consumption reported by U.S. cobalt processors and consumers was 2,300 t of contained cobalt, 8% more than the 2,130 t consumed in 2003. U.S. imports of cobalt waste and scrap were 1,020 t, gross weight, valued at $10.9 million. Seven countries supplied nearly 90% of this material—the United Kingdom (38%); Germany (17%); Ireland (10%); Austria (9%); Canada (7%); Japan (5%); and France (4%). The United States exported 424 t, gross weight, of cobalt waste and scrap valued at $6.7 million. Most of this material was sent to Canada (31%), Belgium and Sweden (16% each), the United Kingdom (11%), Japan (8%), and Germany and the Netherlands (4% each).

Columbium (Niobium)[8]

Columbium (also called niobium) 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 about 75% 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 master alloy are used as feed materials to produce 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-base 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 2004, U.S. apparent consumption of columbium was about 6,800 t compared with about 5,600 t in 2003. 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 the 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

[7]Prepared by Kim B. Shedd.

[8]Prepared by Michael J. Magyar.

usually quickly returned to steel plants and superalloy producers for remelting. Detailed data on the quantities of columbium recycled were not available but may amount to as much as 20% of U.S. columbium apparent consumption (Cunningham, 2004a).

Copper[9]

In 2004, copper recovered from refined or remelted scrap (about 80% from new scrap and 20% from old scrap) composed 29% of the total U.S. copper supply and had an equivalent refined copper value of $2.8 billion. Direct melt scrap was consumed at about 30 brass mills; 20 alloy ingot makers; and 500 foundries, chemical plants, and miscellaneous consumers. Of the 965,000 t of copper recovered from aluminum, copper, nickel, and zinc base scrap, brass mills recovered 73%; brass and bronze ingot makers, 9%; copper smelters and refiners, 5%; and miscellaneous manufacturers (including aluminum and steel alloy producers), foundries, and chemical plants, 13%. Alloyed copper products accounted for about 95% of the total copper recovered from scrap. Secondary refined production in the United States continued its downward trend, declining by about 5% in 2004. Secondary refined production has fallen by about 345,000 t since 1997 owing to contraction of the secondary smelting/refining industry. Copper recovered through the direct melting of scrap to produce copper and copper alloy products, chemicals, and powders rose by about 14,000 t (2%). At brass mills, the leading consumer of direct melt scrap, scrap consumption rose by about 4% and accounted for 57% of their total material supply.

According to data compiled by the International Copper Study Group (2005, p. 15-17), in 2004, estimated world production of secondary refined copper rose by about 250,000 t (14%) to 2.02 Mt following 3 years of decline, and constituted about 13% of global world refined copper production. In addition to copper refined from scrap, significant quantities of scrap were directly melted in the production of copper and copper alloy products at brass mills, foundries, ingot makers, and miscellaneous consumers. With the exception of the United States, most of the major secondary refined copper producers had higher output. In China, secondary refined production rose significantly for the third consecutive year, having increased to 510,000 t in 2004 from about 308,000 t in 2001, largely on the strength of increased imports of copper and copper alloy scrap.

Copper scrap prices generally followed the upward trend in refined copper prices, which rose substantially throughout the year. The New York Mercantile Exchange COMEX Division spot price averaged $1.29 per pound of copper, up sharply from the 2003 average of $0.81 per pound of copper. With higher refined prices, however, the discount of most grades of copper scrap to refined copper increased. According to American Metal Market data, the average discount for refiners No. 2 scrap rose to 21 cents per pound from 11 cents per pound in 2003, and the discount for brass mill No. 1 scrap rose to 2.6 cents per pound from 1.2 cents per pound in 2003. The price discount for No. 2 copper scrap increased sharply in April to 21.3 cents per pound from an average of only 11.5 cents per pound during the first quarter. The rise coincided with industry reports that China, which was the leading destination for domestic scrap exports, had essentially exited from the No. 2 scrap market, and that shipments of scrap were backed-up at Chinese ports (McCann, 2004).

Exports of copper scrap for 2004 totaled 714,000 t, up from 689,000 t in 2003. China (including Hong Kong) was the destination for 67% of domestic scrap exports and, based on import data, accounted for 65% of reported global scrap imports. The United States remained the leading source of scrap, accounting for 19% of global scrap trade (based on reported exports).

On April 7, the Bureau of Industry and Security (BIS), U.S. Department of Commerce, received a joint petition from the Copper and Brass Fabricators Council, Inc. and the Nonferrous Founders' Society, which requested the imposition of export monitoring and export controls on copper scrap and copper-alloy scrap and a public hearing on the issue. The petition was filed under provisions of the Export Administration Act of 1979, as amended, that allowed for an industry, or a segment thereof, which processes metallic materials capable of being recycled to file such a petition (U.S. Department of Commerce, 2004). In their petition, the copper and brass industry contended that the rapid rise of scrap exports to China had created a short supply of scrap materials for domestic consumers and had contributed to higher prices for available supplies. The petitioners argued that not all sectors of their industry were able to substitute copper cathode for scrap as a feed material, and where possible, such substitution imposed economic penalty owing to the higher cost of cathode. The petitioners further claimed that higher raw material costs could not be passed to consumers and that scarcity limited their production and harmed their competitive position. According to the petition, total scrap exports from 1999 to 2003 rose by 138%, and exports to China, which rose by 515% during the same period, accounted for essentially all of the increase. The petitioners requested that export quotas be set at the mean volume of exports for the period 1996-2000, 380,000 t, about 50% of the 2003 level (U.S. Department of Commerce, 2004b§).

In July, the BIS issued its ruling on the petition in which it determined that the short supply criteria had not been met and that neither monitoring nor controls were warranted. In its determination, the U.S. Department of Commerce concluded that:

- Though the volume of exports of copper-base scrap increased significantly during the study period, the increase was somewhat less significant when considered in relation to domestic demand and the erosion of the secondary smelting industry.
- Copper scrap prices did increase significantly, but the world market for copper cathode, not the level of U.S. exports of copper-base scrap, was the most important determinant in the fluctuations of domestic scrap prices.
- The evidence did not demonstrate the existence of a scrap shortage, nor did it demonstrate a significant adverse effect on the national economy or sector thereof.

The Commerce Department indicated, however, that it would work to refine schedule B classifications for copper-

[9]Prepared by Daniel L. Edelstein.

base scrap exports in order to better delineate the varieties of scrap being exported; review the new scrap export data in the coming year; and work closely with the office of the U.S. Trade Representative to address any foreign government practices that are distorting trade in copper-base scrap (U.S. Department of Commerce, 2004a§). New schedule B classifications were subsequently implemented for 2005.

The secondary smelting and refining industry, which has endured a continual decline in recent years, received a boost when American Iron & Metal Co. Inc. (Montreal, Quebec, Canada) restarted its Warrenton, MO, fire refinery, the only remaining nonintegrated secondary copper refinery in the United States, during the second half of the year. American Iron & Metal acquired Warrenton from Philip Services Corp. (Houston, TX) in 2000 and operated it intermittently until yearend 2002. Operating as the newly formed Warrenton Copper LLC, the plant consumed No. 2 copper scrap to produce fire refined ingot (McCann, 2004§).

Gallium[10]

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)-base 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 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 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, and 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).

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). In addition to reprocessing scrap, several companies have the ability to reclaim GaAs wafers, primarily through stripping and polishing operations.

Gold[11]

Old scrap consists of gold-containing products that have been discarded after use, and generally contributes 13% to 25% of the U.S. gold supply. 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. In many areas of the world, especially in those areas where the holding of gold is encouraged by tradition, secondary gold, that which is 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.

Domestic consumption of old and new gold scrap was 62,000 kg and 50,000 kg, respectively, in 2004. These data, which were collected by the USGS, included 20,000 kg of old imported scrap. In 2004, U.S. exports of gold scrap increased by 356%, while imports increased by 37%. As it has been for many years, the United States was a net exporter of gold scrap in 2004. In 2004, the unit value of imported waste and scrap gold was $243 per troy ounce, and exported, $35 per ounce; the average price according to Platts Metals Week was $411 per ounce.

Indium[12]

Recycling of indium scrap continued its steady rise of recent years, aided by the dramatic indium price increases (Platts Metals Week, 2004).

An important domestic source of indium remains an estimated 37 t of indium contained as a flue dust at a site in Kellogg, ID, where the Bunker Hill Company once operated a lead and zinc smelter (Platts Metals Week, 2001). Although there has been occasional interest in processing the material at this site to recover indium and other metals, the priority has been the rehabilitation of the sections near residential areas (U.S. Environmental Protection Agency, 2004§).

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[10]Prepared by Deborah A. Kramer.

[11]Prepared by Micheal W. George.

[12]Prepared by James F. Carlin, Jr.,

Worldwide, the central aspect of recycling on the supply side has been the capability of countries to recycle indium-containing electronic components, which tend to have a relatively short lifecycle. Japan and other East Asian countries are at the forefront of these efforts. Recent trends in sharply rising indium prices combined with moderation in primary indium capacity have added an extra incentive to the recovery of secondary indium. Sustained high prices should encourage increased recycling and primary production. An estimated 50% of consumed indium-tin oxide comes from recycled sources, and is projected to rise in coming years (Roskill's Letter from Japan, 2004).

In the United States, small amounts of new indium scrap were recycled in 2004. The infrastructure for collection of indium-containing products is not well established in the United States. Recycling of indium could expand significantly in the United States if the price of indium continues to increase.

Iron and Steel[13]

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 remelting and casting 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% (Steel Recycling Institute, 2005b§).

The vast quantity of ferrous scrap available for recycling comprises home, prompt, and obsolete scrap. Prompt or industrial scrap is generated from manufacturing plants that make steel products. Its chemical and physical characteristics are known, and it is transported 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 and defective products are collected and quickly recycled back into the steel furnace because their chemical compositions are known. The availability of home scrap has been declining as new and more efficient methods of casting have been adopted by the industry. Obsolete, old, or postconsumer scrap is also available for recycling. The leading source is discarded automobiles, 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, the primary source of obsolete steel is the automobile (Steel Recycling Institute, 2005a§). Of the ferrous metals used to make a typical 2004 U.S. family vehicle, 65% was recycled. About 12,000 car dismantlers and 3,000 scrap processors produced about 14 Mt of iron and steel scrap for recycling in 2004—enough steel to produce nearly 13.5 million new cars. The recycling rate of automobile scrap steel was nearly 102% in 2004 compared with 102.9% in 2003. 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 relative contents of the alloying 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 (BOF), electric-arc furnaces (EAF), and to a minor extent, in blast furnaces. The proportion of scrap in the charge 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 2004, BOFs accounted for 48% of United States steel production, while using only 25% of scrap consumed (American Iron and Steel Institute, 2004, p. 86). During the same period, EAFs accounted for 52% of U.S. steel production while using 75% of scrap consumed. Scrap was also consumed in blast furnaces and other types of furnace.

Iron and steel scrap is more than just an economically beneficial additional resource for steelmakers. Recycling conserves energy, landfill space, and natural resources. Recovery of 1 t of steel from scrap conserves an estimated 1,130 kg of iron ore, 635 kg of coal, and 54 kg of limestone. Each year, steel recycling 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, 2005a§).

During 2004, steel recycling rates were 102% for automobiles, 98% for construction structural beams and plates, 90% for appliances, 62% for steel cans, and nearly 71% overall (Steel Recycling Institute, 2005b§). Ferrous scrap is an important raw material for the steel and foundry industries. Because scrap comes from such sources as old buildings, industrial machinery, discarded cars and consumer durables, and manufacturing operations, the mature industrialized economies are the main exporters of scrap.

The main trade flows of scrap are from the heavily industrialized and developed countries of Europe and North America to lesser developed steelmaking countries. The United States was the leading exporting country of iron and steel scrap in 2003, as reported by the International Iron and Steel Institute (2004, p. 102), followed by the United Kingdom, Russia, Germany, Japan, France, and the Netherlands. The most significant importing nations were, in decreasing order of importance, Turkey, China, Belgium and Luxembourg, Spain, the Republic of Korea, Italy, Germany, France, the United States, and Taiwan (International Iron and Steel Institute, 2004, p. 104).

[13]Prepared by Michael D. Fenton.

The U.S. trade surplus for ferrous scrap was 7.0 Mt in 2004 (U.S. Census Bureau, unpub. data, 2004). U.S. exports of carbon steel and cast-iron scrap amounting to 9.6 Mt went to 74 countries. The largest tonnages went to Canada, China, Mexico, and the Republic of Korea. U.S. exports of stainless steel scrap amounting to 503,000 t went to 50 countries. The largest tonnages went to China, Finland, the Republic of Korea, and Taiwan. U.S. exports of alloy steel scrap (excluding stainless steel) amounting to 1.8 Mt were shipped to 52 countries. The largest tonnages went to Canada, China, and Mexico.

Lead[14]

About 88% of the 1.26 Mt of refined lead produced in the United States in 2004 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 (SLI) 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. Lead-acid batteries account for 93.7% of lead produced from secondary sources, leaving only about 6.3% for all other sources, including building construction materials, cable covering, drosses and residues (new scrap) from primary smelter-refinery operations, and solder.

In 2004, there were 12 companies in the United States producing secondary lead, exclusive of that produced from copper-base scrap. Of the 1.11 Mt of lead recycled in 2004, about 99.6% was produced by 7 companies operating 14 secondary smelter-refineries (with capacities of more than 20,000 t/yr) in Alabama, California, Florida, Indiana, Louisiana, Minnesota, Missouri, New York, Pennsylvania, 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 87% of the reported consumption of lead in the United States in 2004.

During 2004, the United States exported about 56,300 t of lead-bearing scrap, which included whole spent lead-acid batteries as well as nonbattery forms. This level of exported scrap lead was a 12-year low, indicating a high level of demand for scrap lead at U.S. secondary smelters. Imported lead-bearing scrap in all forms totaled about 4,770 t during the year.

The recovery of lead from spent lead-acid batteries and other lead scrap at secondary smelters in 2004 was sufficient to meet by about 86% 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 2004, 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 6.2 cents per pound and mixed hard lead and wheel weights averaged 8.5 cents per pound at yearend 2004 (American Metal Market, 2004). The average price for refined lead produced at secondary smelters in 2004 was about 56.2 cents per pound, a 24% increase from the 2003 price of 45.3 cents per pound (Platts Metals Week, 2005).

North American replacement SLI automotive battery shipments grew by approximately 2.4% in 2004 to 89.7 million batteries. Original equipment SLI battery shipments also increased, by 6% (20.8 million) (Battery Man, The, 2005§). In 2004, the U.S. imported 13,200,000 lead-acid batteries of all sizes from Mexico—95% was SLI batteries for cars and light trucks. Also, there are increasing imports from China, the Republic of Korea, and Brazil, in decreasing order of importance. Using trade data from the U.S. Department of Commerce and the U.S. International Trade Commission, in 2004 the United States imported (net import) more than 275,000 t of lead contained in lead-acid batteries—for the past 5 years more than 1 Mt of contained lead. Most of this material will be feed for secondary smelters in the near future, further squeezing out primary lead production.

Production of refined lead recycled from old scrap decreased by about 2% in 2004 compared with production in 2003. Stocks of refined secondary lead held by producers and battery manufacturers decreased by about 30% at yearend 2004 compared with those of yearend 2003. The lead-acid battery industry recycled 99.2% of the available lead scrap from spent lead-acid batteries during the period 1999 through 2003, according to a report issued by Chicago, IL-base Battery Council International in mid-2005. Lead-acid batteries remained the United States most highly recycled consumer product. Historically, the recycling rate of battery lead has consistently ranked higher than other recyclable materials (Battery Council International, 2005).

Magnesium[15]

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, and dross) 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 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

[14]Prepared by Peter N. Gabby.

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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).

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).

Manganese[16]

Scrap recovery specifically for manganese is insignificant. To a large extent, manganese is recycled incidentally as a minor constituent of other metal alloys recycling, 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 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 in 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 2004, the amount of manganese recycled in the aluminum industry was estimated to be about 1% of manganese apparent consumption, based on the reported weight of aluminum cans consumed (734,000 t) and the average beverage can manganese content of 0.92% (Plunkert, 2004; Jones, 2001§). In the future, small additional amounts of manganese could be recovered through widespread recycling of dry cell batteries (Watson, Andersen, and Holt, 1998).

Mercury[17]

In 2004, reclamation and recycling of mercury from used mercury-containing products was vital to the continued, though declining, use of this metal. Mercury was reclaimed from a declining supply of mercury-containing waste by treatment in multistep, high-temperature retorts in which the mercury is volatized and then condensed for purification and sale (Brooks and Matos, 2005§). If mercury-containing products are improperly recycled, then companies may face fines, prosecution, and long-term liability. Some mercury-containing waste, such as chlorine-caustic soda sludge or mercury-containing debris may have been land filled in the United States or in Canada. Chlorine-caustic soda sludge was included on a list of waste types accepted at a dedicated placement site in Canada (Stablex Canada Inc., 2004§). In 2003, 1,660 t of undefined amalgam that could have been recycled was exported, mainly to Canada (455 t) and Mexico (812 t). In 2004, 603 t of amalgam was exported, mainly to Canada (49 t) and Mexico (194 t).

The domestic recycling industry was concerned that the environment was threatened by exports of mercury-containing waste that was shipped to landfills in Canada without retorting or reclamation of the contained mercury. A 1994 U.S. Environmental Protection Agency (EPA) regulation indicated that treatment standards for all mercury-containing debris in excess of 60 millimeters were to be suspended. This unclear regulation, which is known in the hazardous waste and recycling industry as the "debris loophole," permits unquantified amounts of secondary mercury or mercury-containing products to be landfilled in the United States (U.S. Environmental Protection Agency, 1994; Richard C. Fortuna, environmental consultant, Strategic Environmental Analysis, L.C., written commun., October 8, 2004). Landfilling of mercury-containing material without reclamation of the mercury was a major environmental and recycling industry concern. Some mercury was recycled

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“in-plant” by the chlorine-caustic soda industry, the chief end user of mercury in the United States. The yearly purchase of replacement mercury by the chlorine-caustic soda industry indicates that some mercury was released from these plants. Diaphragm and membrane cells are nonmercury alternatives for chlorine and caustic soda production (Roskill Information Services Ltd., 1990, p. 65). The ultimate closure of the nine remaining mercury-base chlorine-caustic soda plants could make approximately 3,000 t of mercury available for recycling (Raloff, 2003§).

Mercury used in tilt switches in cars, fluorescent lamps, and thermostats was of environmental concern because of the potential for mercury releases during demolition, scraping, and waste treatment. Mercury was also recovered and recycled from unbroken fluorescent lamps.

The companies that recycled mercury in 2004 included AERC.com, Inc., Allentown, PA; Bethlehem Apparatus Company, Bethlehem, PA; D.F. Goldsmith Chemical and Metal Corporation, Evanston, IL; Mercury Waste Solutions, Mankato, MN; and Onyx Environmental Services, Lombard, IL.

Molybdenum[18]

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 captured. 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 reported, 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, 2004).

Nickel[19]

Austenitic stainless steel scrap is the leading source of secondary nickel for the United States, accounting for about 87% of the 83,300 t of nickel reclaimed in 2004. An additional 1% came from the recycling of alloy steel scrap. The combined 88% 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 (furnace dust, grindings, and mill scale). The remaining 12% of the scrap falls into several categories—superalloys, copper-nickel alloys, aluminum-nickel alloys, and pure nickel metal as described below. After segregation, each of the specialty scrap types is routed along its own separate and unique processing path designed to maximize recycling profits.

A global supply deficit of primary nickel, coupled with rising energy and refining costs, led to sharply higher prices for cut cathode and other forms of primary nickel for the third consecutive year. World demand and prices for austenitic stainless steel scrap followed suit. For the fourth consecutive year, there was not enough quality 18/8 stainless steel scrap to meet global melt shop demand. Scrap availability has been rising, but at a slightly lower rate than stainless steel production. This situation is not expected to change in the near future because world demand for austenitic stainless steel is estimated to be growing at a rate of 3% to 6% per year (Hunter, 2002; Kaumanns, 2005). World production of total stainless steel was about 24.6 Mt (gross weight) in 2004, up 7% from 2003 levels. An estimated 16.0 t, or 65%, was alloyed with nickel (Kaumanns, 2005). The overall scrap ratio for the Western World was expected to remain at 45% because of the constricted supply of scrap.

Much of the growth in demand for stainless steel and nickel continues to occur in East Asia. Japan and China were the leading consumers of stainless steel in 2004, followed by the United States. Russia continued to export about 500,000 t/yr of stainless steel scrap, or about 42,000 t/yr of contained nickel, despite a 15% export duty on the material (Nijkerk, 2004). In 2003, most of the Russian scrap went to stainless steel operations in Finland, Germany, and Sweden.

The United States produced 1.55 Mt (gross weight) of austenitic stainless steel in 2004, almost 13% greater than the 1.37 Mt in 2003. U.S. exports of stainless steel scrap declined to 35,900 t of contained nickel from 37,800 t in 2003, a decrease of 5%. Record high U.S. production of stainless steel and a sharp rise in domestic scrap prices were partially responsible for the decrease in exports. The annual average price for 18/8 scrap in bundles was $1,450 per metric ton (Pittsburgh, PA), up 56% from $927 in 2003. China was the leading importing nation of U.S. stainless scrap, purchasing 11,800 t of contained nickel in 2004. The Republic of Korea was in second place with 6,670 t and was followed by Finland, with 5,400 t. Taiwan, the leading purchaser in 2003, was in fourth place, with 3,240 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 4% of the nickel reclaimed in 2004. 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.

The remaining 8% of reclaimed nickel came from nickel-base superalloy scrap and pure nickel metal 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

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and cleaning and later returned to the producers for remelting. Because of the stringent specifications for INCONEL 718, WASPALLOY, and similar aerospace-grade superalloys, much of the superalloy scrap is not suitable for direct recycling. This material is sold, instead, to specialty alloy casting companies, stainless steel producers, or steel foundries.

Platinum-Group Metals[20]

For most platinum-group metal (PGM) applications, the actual loss during use of the metal is small, and hence the availability of PGMs in old scrap contributes greatly to the economics of PGM use. Typical sources of PGM for secondary refining include catalysts, electronic scrap, jewelry, and used equipment from the glass industry.

In 2004, recovery and recycling of automobile catalysts continued to provide a growing secondary source of PGMs. The strength of the price of platinum in 2004, which averaged $848.76 per troy ounce, helped support the profitability of the recovery and recycling businesses. Despite the price increase in 2004, domestic recovery of platinum from catalytic converters rose by only 400 kg to an estimated 13,600 kg of platinum.

Stillwater Mining Company announced in late 2004 that it had entered into a supply contract that would greatly increase its PGM recycling. PGM scrap was obtained primarily from spent automobile catalysts with additional material from spent catalytic materials from oil refineries. In 2004, Stillwater increased its secondary recovery of PGMs to 5,130 kg—3,080 kg of platinum, 1,650 kg of palladium, and 404 kg of rhodium (Stillwater Mining Company, 2005, p. 7).

Increased recovery and recycling of automobile catalysts were most noticeable in Western Europe, where improved collection and processing of scrap catalytic converters resulted in the recovery of 4,400 kg of platinum and 3,400 kg of palladium. For several years, the recovery of PGM from scrap catalytic converters in the EU has been increasing owing to high PGMs prices and the introduction of legislation to increase scrap-vehicle recycling. The EU end-of-life vehicle recycling directive was to become effective in 2005 and aimed to increase the rate of recovery and reuse of materials to 85% per vehicle by weight by 2006. In several countries, effectively 100% of the cars being recycled were equipped with catalytic converters containing PGM alloys. As for the remaining EU countries, because catalytic converters have only been required on all new gasoline cars since 1993, the proportion of automobiles fitted with catalytic converters being scrapped is increasing as greater numbers of these vehicles reach the end of their lives. Greater quantities of PGMs also were recovered from automobile catalysts in South America and Asia because of the higher price (Kendall, 2005, p. 22-23).

Selenium[21]

In 2004, 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 selenium. 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.

Tantalum[22]

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 tantalum is consumed by 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 to make carbide tools for metalworking equipment and 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 2004, U.S. apparent consumption of tantalum was about 650 t compared with 520 t in 2003; scrap (from various sources) was about 20% of the apparent consumption. Tantalum was mostly recycled from new scrap 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, 2004b).

Tin[23]

In 2004, 16% of the domestic apparent supply of tin metal was recovered from scrap (table 1). Old tin scrap was collected at hundreds of domestic scrap yards, two detinning plants, and most municipal collection-recycling centers. New tin scrap was generated mainly in the tin mills of six steel plants, scores of canmaking 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 canmaking 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, and solder); 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

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recycling of used tin cans, which has been an important raw material for the Nation's steel industry during the past 20 years.

Titanium[24]

In the United States, titanium ingot producers (recyclers) included Allvac (Allegheny Technologies Inc.), Howmet Corp. (Alcoa Inc.), RMI Titanium Co. (RTI International Metals, Inc.), and Titanium Metals Corp. Scrap turnings and bulk scrap are generated during the melting, forging, casting, and fabrication of titanium components. In addition, old scrap is recovered from obsolete aircraft parts and heat exchangers. Titanium scrap is used as an alternative to titanium sponge (virgin metal) in the production of titanium ingot. Scrap is recycled into titanium ingot either with or without sponge using traditional vacuum-arc-reduction and cold-hearth melting practices.

Driven by increased demand from the commercial aerospace industry, consumption of scrap for the production of titanium ingot increased by 29% in 2004 compared with that of 2003. Compared with sponge, scrap supplied about 47% of the titanium required for ingot production. Although no data were 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. 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 2004, the United States was a net exporter of scrap with scrap exports exceeding imports by 931 t. Imports and exports of titanium scrap increased significantly compared with those of 2003.

A significant quantity of titanium in the form of sponge, scrap, and ferrotitanium is consumed in the steel and nonferrous alloy industries. Consumption by the steel industry is largely associated with the production of stainless steels and is used for deoxidation, grain-size control, or carbon and nitrogen control and stabilization typically in interstitial-free, stainless, and high-strength low-alloy steels. Reported domestic consumption of titanium products in steel and other alloys was 10,200 t, a 16% increase compared with that of 2003.

Owing to increased demand for the production of titanium and specialty steel, the published price range for titanium scrap turnings increased to between $3.80 and $4.00 per pound at yearend 2004 from between $1.50 and $1.70 per pound at yearend 2003. Yearend prices for ferrotitanium also significantly increased to between $6.35 and $6.45 per pound in 2004 from between $3.00 and $3.20 per pound in 2003.

Tungsten[25]

In 2004, an estimated 25% to 30% of world tungsten supply was from recycled materials (Maby, 2004, p. 4). Tungsten-bearing scrap originated during manufacture and/or after use in a wide variety of applications, including catalysts used in the production of chemicals and petroleum and for cleaning powerplant stack gases; cemented carbides for cutting and wear-resistant applications; heavy-metal alloys for armaments, heat sinks, radiation shielding, and weights and counterweights; high-speed and tool steels; mill products made from metal powder, such as electrical contacts, heating elements, protective shields, sputtering targets, switches, and wires and filaments for lamps; and specialty alloys, such as superalloys for turbine engines and wear-resistant alloys. Depending on the type and quality of the scrap, it could 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 (Shedd, 2005§).

Several processes were used to recycle cemented carbide scrap. Some of them resulted in tungsten carbide powder mixed with cobalt, which could be used to make new cemented carbide parts. In other processes, the cobalt was recovered separately, and the tungsten was converted to the intermediate product ammonium paratungstate from which tungsten carbide powder, chemicals, or metal powder could be produced. The preferred use for solid pure tungsten metal scrap was as a source of tungsten in the manufacture of superalloys; the preferred use for pure tungsten metal scrap in powder form was as a source of tungsten for the manufacture of cast or menstruum tungsten carbide. Most heavy-metal alloy manufacturing scrap was recycled as home scrap to a prealloyed powder, but it could also be chemically converted to ammonium paratungstate or used to produce macrocrystalline tungsten carbide or ferrotungsten, tool steels, or tungsten melting base. Scrap from the steel and specialty alloy (for example stellites and superalloys) industries was recycled by the steel and specialty alloy industries, respectively (Shedd, 2005§).

In 2004, scrap consumption by U.S. tungsten processors and consumers contained 4,000 t of tungsten, which was a decrease of 3% from the 4,130 t (revised) consumed in 2003. The United States imported 1,150 t of tungsten contained in waste and scrap valued at $8.7 million, 3% more than the tungsten contained in waste and scrap imports in 2003. Six countries supplied most of these imports—Germany, 42%; Japan, 14%; China, 11%; Hong Kong, 10%; Canada, 5%; and the United Kingdom, 4%. The United States exported an estimated 525 t of tungsten in waste and scrap valued at $3.7 million, which was 25% less than the estimated 702 t of contained tungsten in waste and scrap exported in 2003. The leading destinations for these exports were Germany, 23%; India, 21%; Belgium, 14%; China, 11%; the United Kingdom, 10%; the Netherlands, 8%; and Canada, 4%.

Vanadium[26]

The principal use of vanadium is as an alloying element in steel, either as a vanadium oxide or as ferrovanadium. 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. Any new scrap generated in either the production of alloys or catalysts was likely reused

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internally. Vanadium was also used in catalysts; however, it is estimated that catalyst consumption accounts for less than 1% of the U.S. vanadium consumption. Vanadium is primarily recovered from vanadium-bearing slag after titaniferous magnetite ore is processed to produce liquid pig iron in China, Russia, and South Africa. This slag was sporadically imported into the United States and further processed to produce a 40% to 50% vanadium-content ferrovanadium. Vanadium oxides, recovered from petroleum residues, ashes, and poisoned refinery catalysts, however, account for the most significant source of vanadium in the United States as there is no primary production. Two plants in Arkansas and Texas account for most of the vanadium oxide recovered from these vanadium-bearing materials. Vanadium oxides were used to produce catalysts, chemicals, and 75% to 80% vanadium-content ferrovanadium.

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TABLE 1
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS[1]

	Quantity of metal (metric tons)					Value of metal (thousands)			
Year	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]									
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	1,210,000	2,970,000	7,990,000	37	2,670,000	1,830,000	4,500,000	12,100,000
2002	1,750,000	1,170,000	2,930,000	8,070,000	36	2,510,000	1,680,000	4,190,000	11,500,000
2003	1,750,000	1,070,000	2,820,000	7,880,000	36	2,620,000	1,610,000	4,230,000	11,800,000
2004	1,870,000	1,160,000	3,030,000	8,460,000	36	3,640,000	2,140,000	5,600,000	15,700,000
Chromium:[8]									
2000[r]	NA	NA	161,000	479,000	34	NA	NA	114,000	439,000
2001[r]	NA	NA	141,000	344,000	41	NA	NA	81,900	223,000
2002[r]	NA	NA	174,000	479,000	36	NA	NA	95,100	293,000
2003[r]	NA	NA	180,000	532,000	34	NA	NA	139,000	429,000
2004	NA	NA	168,000	555,000	30	NA	NA	207,000	681,000
Copper:[9]									
2000	955,000	358,000	1,310,000	4,050,000	32.5	1,860,000	697,000	2,550,000	7,860,000
2001	833,000	317,000	1,150,000	3,340,000	34.4	1,410,000	536,000	1,950,000	5,660,000
2002	842,000	208,000	1,050,000	3,450,000	30.4	1,410,000	348,000	1,760,000	5,770,000
2003	738,000	206,000	944,000	3,170,000	29.8	1,390,000	387,000	1,770,000	5,950,000
2004	774,000	191,000	965,000	3,330,000	28.9	2,290,000	565,000	2,850,000	9,830,000
Iron and steel:[10]									
2000	NA	NA	74,600,000 [r]	134,000,000	55	NA	NA	7,100,000	12,800,000
2001	NA	NA	70,600,000	118,000,000	60	NA	NA	5,320,000	8,880,000
2002[11]	NA	NA	70,000,000	119,000,000	58	NA	NA	6,450,000 [r]	10,200,000
2003[11]	NA	NA	65,500,000	117,000,000	56 [r]	NA	NA	7,860,000 [r]	13,200,000 [r]
2004[11]	NA	NA	66,500,000	132,000,000	51	NA	NA	13,400,000	24,900,000
Lead:[12]									
2000	46,900 [r]	1,080,000	1,130,000 [r]	1,730,000 [r]	76.8 [r]	45,100 [r]	1,040,000	1,080,000	1,660,000 [r]
2001	55,300 [r]	1,040,000	1,100,000 [r]	1,670,000 [r]	75.6 [r]	53,200 [r]	1,010,000	1,060,000 [r]	1,610,000 [r]
2002	42,600 [r]	1,070,000	1,120,000 [r]	1,540,000	81.2 [r]	40,900 [r]	1,030,000	1,070,000 [r]	1,480,000
2003[r]	19,300	1,120,000	1,140,000	1,520,000	77.4	18,600	1,080,000	1,100,000	1,470,000
2004	12,900	1,100,000	1,110,000	1,440,000	83.7	15,600	1,360,000	1,350,000	1,750,000
Magnesium:[13]									
2000	52,200	30,100	82,300	199,000	41	158,000	90,800	248,000	601,000
2001	38,600	27,200	65,800	151,000	44	106,000	75,000	181,000	416,000
2002	47,100	26,400	73,600	148,000	50	126,000	70,500	196,000	395,000
2003	44,700	25,400 [r]	70,100 [r]	152,000	46	107,000	60,900 [r]	168,000	366,000
2004	51,600	20,500	72,100	181,000	40	167,000	66,400	234,000	586,000
Nickel:[14]									
2000	NA	NA	86,500 [r]	233,000 [r]	37 [r]	NA	NA	747,000 [r]	2,020,000 [r]
2001	NA	NA	81,200 [r]	210,000 [r]	39 [r]	NA	NA	483,000 [r]	1,250,000 [r]
2002[r]	NA	NA	83,900 [r]	205,000 [r]	41 [r]	NA	NA	568,000 [r]	1,380,000 [r]
2003	NA	NA	83,500 [r]	200,000 [r]	42 [r]	NA	NA	804,000 [r]	1,930,000 [r]
2004	NA	NA	83,300	212,000	39	NA	NA	1,150,000	2,930,000

See footnotes at end of table.

TABLE 1—Continued

SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS[1]

Year	Quantity of metal (metric tons)				Percentage recycled	Value of metal (thousands)			
	Recycled from new scrap[2]	Recycled from old scrap[3]	Recycled[4]	Apparent supply[5]		Recycled from new scrap[2]	Recycled from old scrap[3]	Recycled[4]	Apparent supply[6]
Tin:[15]									
2000	9,140	6,560	15,700	54,500	29	74,400	53,500	128,000	443,000
2001	7,210	6,700	13,900	46,300	30	24,400	29,900	54,300	316,000
2002	3,790	6,760	10,600	49,100	22	18,400	40,600	59,000	307,000
2003[r]	3,570	5,500	9,070	41,500	22	26,800	41,200	68,000	311,000
2004	3,590	4,850	8,440	52,600	16	44,000	59,400	103,000	645,000
Titanium:[16]									
2000	NA	NA	18,500	W	50	NA	NA	38,200 [e]	NA
2001	NA	NA	17,002	W	39	NA	NA	35,200 [e]	NA
2002	NA	NA	11,603	W	40	NA	NA	25,573 [e]	NA
2003	NA	NA	14,340	W	46	NA	NA	48,000 [e]	NA
2004	NA	NA	18,500	W	47	NA	NA	127,000 [e]	NA
Zinc:[17]									
2000	369,000	70,300	439,000	1,630,000	26.9	454,000	90,000	544,000	2,020,000
2001[r]	317,000	57,000	375,000	1,420,000	26.4	307,000	55,200	362,000	1,380,000
2002	319,000	47,300	366,000	1,420,000	25.8	272,000	40,300	312,000	1,210,000
2003	295,000	50,300	345,000	1,340,000	25.8	264,000	45,100	309,000	1,200,000
2004	302,000	47,100	349,000	1,400,000	24.9	421,000	65,600	486,000	1,950,000

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

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

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

[3]Scrap that results from consumer products.

[4]Metal recovered from new plus old scrap.

[5]Apparent 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.

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

[7]Quantity 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.

[8]Chromium 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.

[9]Includes 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.

[10]Iron 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.

[11]Before 2003, monetary value based on U.S. annual average composite price for No. 1 heavy-melting steel calculated from prices published in American Metal Market. After 2002, monetary value based on mass-weighted average of steel trade (exports plus imports) of selected Harmonized Tariff Schedule of the United States (HTS) categories. Recycled unit value based on HTS 7204 by year and per metric ton was 2003—$172 and 2004—$252. Steel production unit value based in HTS 7206 and 7207 by year and per metric ton was 2003—$259; 2004—$679. Apparent supply value is mass weighted-average of recycled production unit values.

[12]Lead processors are segregated by primary and secondary producers. This segregation permits inclusion of stock changes for secondary producers. Monetary value o scrap and apparent supply estimated based upon average quoted price of common lead.

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

TABLE 1—Continued

SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS[1]

[14]Nickel 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 briquets, cathode, flake, pellets, and powder.
- 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.

[15]Monetary value based on Platts Metals Week composite price for tin.

[16]Percentage recycled based on titanium scrap consumed divided by primary sponge and scrap consumption.

[17]Monetary 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 METALS[1]

	Exports			Imports for consumption		
	Quantity			Quantity		
Year	Gross weight (metric tons)	Contained weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Contained weight (metric tons)	Value (thousands)
Aluminum:						
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
2003	577,000	NA	633,000	440,000	NA	496,000
2004	660,000	NA	773,000	535,000	NA	655,000
Chromium:[2]						
2000	469,000	80,800	323,000	66,100	19,500	94,900
2001	439,000	75,600	281,000	50,500	15,400	74,100
2002	343,000	59,000	259,000	88,500	21,200	92,200
2003	505,000	86,700	394,000	97,700	23,700	115,000
2004	479,000	82,200	565,000	156,000	34,500	216,000
Copper:[3]						
2000	485,000	395,000	537,000	144,000	112,000	180,000 r
2001	534,000	439,000	538,000	115,000	91,100	140,000 r
2002	511,000	407,000	509,000	100,000	80,300	124,000 r
2003	689,000	558,000	664,000	90,600	70,700	121,000 r
2004	714,000	578,000	882,000	102,000	79,800	183,000

See footnotes at end of table.

TABLE 2—Continued

SALIENT U.S. RECYCLING TRADE STATISTICS FOR SELECTED METALS[1]

	Exports			Imports for consumption		
	Quantity			Quantity		
Year	Gross weight (metric tons)	Contained weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Contained weight (metric tons)	Value (thousands)
Iron and steel:						
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
2003	10,900,000	10,900,000	1,960,000	3,690,000	3,690,000	556,000
2004	11,800,000	11,800,000	2,930,000	4,790,000	4,790,000	1,280,000
Lead:						
2000	71,600	71,600	13,200	13,400	12,100	5,140
2001	108,000	108,000	24,900	10,700	10,000	4,260
2002	106,000	106,000	23,300	2,880	2,570	1,740
2003	92,800	92,800	23,300	4,970	4,600	2,460
2004	56,300	56,300	14,800	5,320	4,770	3,510
Magnesium:						
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
2003	5,040	5,040	11,800	16,200	16,200	22,000
2004	4,790	4,790	11,300	11,700	11,700	17,600
Nickel:[4]						
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
2003	1,410,000	50,900	704,000	230,000	12,000	138,000
2004	2,240,000	55,200	995,000	453,000	20,000	328,000
Tin:						
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
2003	5,040	5,040	8,630	921	921	686
2004	9,310	9,310	13,200	1,950	1,950	1,700
Titanium:						
2000	5,060	5,060	$12,700	7,550	7,550	$24,100
2001	7,500	7,500	18,300	11,600	11,600	41,200
2002	6,000	6,000	14,200	6,270	6,270	17,800
2003	5,320	5,320	29,200	5,550	5,550	19,700
2004	9,760	9,760	56,000	8,830	8,830	53,600
Zinc:						
2000	21,900	NA	12,800	36,500	NA	16,200
2001	26,800	NA	14,200	39,300	NA	11,600
2002	19,800	NA	11,200	31,200	NA	9,530
2003	32,300	NA	23,300	10,300	NA	5,740
2004	40,300	NA	39,400	10,800	NA	7,740

[r]Revised. NA Not available.

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

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

[3]For 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%.

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