

# RECYCLING—METALS

By Staff

## Introduction<sup>1</sup>

In 2003, the United States recycled 67 million metric tons (Mt) of metal. 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 (from the Earth) and secondary metal (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 in terms of energy savings, reduced volumes of waste, and reduced emissions associated with energy savings. The following comments are based on salient U.S. apparent supply and recycling statistics for selected metals listed in table 1. In 2003, metal apparent supply was 132 Mt. Recycling contributed 66.9 Mt to metal apparent supply, an amount equivalent to 50.8% 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 88.8% of metal apparent supply and 91.7% of recycled metal. By weight, aluminum accounted for the second leading share of metal apparent supply, 5.98%; and the second leading share of recycled metal, 4.22%. Measured as recycled metal as a percentage of its own apparent supply, lead was the most recycled metal (80%), followed by iron and steel (52%); the least recycled were tin (19%) and zinc (26%).

The following comments are based on U.S. trade statistics for selected metals listed in table 2. The United States exported 14.2 Mt of scrap metal valued at \$4.45 billion in 2003, while it imported 4.59 Mt of scrap metal valued at \$1.48 billion. Based on the total quantity of recycled metal exports, iron and steel dominated, accounting for 76.6%; nickel was second at 9.96%; while aluminum, chromium, and copper accounted for about 4% each. Based on the total quantity of recycled metal imports for consumption, iron and steel dominated, accounting for 80%; aluminum accounted for 9.60%.

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, and 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 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), 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, internal scrap, and external scrap, has evolved to describe scrap generated by a wide variety of 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<sup>2</sup>

Aluminum recovered from purchased scrap decreased slightly to 2.82 Mt. 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 55% of the reported old scrap consumption in 2003.

According to figures released by the Aluminum Association Inc., the Can Manufacturers Institute, and the Institute of Scrap Recycling Industries, 49.9 billion aluminum UBCs were recycled in the United States in 2003, for a beverage can recycling rate of 50%. For 22 of the past 23 years, the rate has equaled or exceeded 50% (Aluminum Association Inc., 2004).

Purchase prices for aluminum scrap, as quoted by American Metal Market, also fluctuated but closed at higher levels than those at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 57 to 58 cents per pound; old sheet and cast aluminum, 54 to 55 cents per pound; and clean, dry aluminum turnings, 53 to 54 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 49 to 51 cents per pound and closed the year at 53.5 to 55 cents per pound. The

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<sup>1</sup>Prepared by John F. Papp.

<sup>2</sup>Prepared by Patricia A. Plunkert.

annual average American Metal Market price for aluminum UBCs increased to 50.5 cents per pound in 2003 from 47.4 cents per pound in 2002.

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 2003 were as follows: alloy A380 (3% zinc content), 84 cents per pound; alloy B380 (1% zinc content), 85.3 cents per pound; alloy A360 (0.6% copper content), 88.2 cents per pound; alloy A413 (0.6% copper content), 88.1 cents per pound; and alloy 319, 87.6 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 London Metal Exchange (LME) cash price for a similar A380 alloy was 63.5 cents per pound and LME's annual average North American Special Aluminium Alloy Contract cash price for 2003 was 63 cents per pound.

### **Beryllium<sup>3</sup>**

About 75% of domestic beryllium consumption was in the form of beryllium-copper alloys that are used mostly in electrical and electronic components. A small amount of 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 of 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 compose as much as 10% of U.S. beryllium apparent consumption (Cunningham, 2004<sup>4</sup>).

### **Cadmium<sup>5</sup>**

The amounts of secondary or recycled cadmium are 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 publicly available 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 2003, 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 is used in nickel-cadmium (NiCd) batteries, and because batteries are easy to recycle, most of the secondary cadmium comes from spent NiCd batteries. In 1992 (the latest available data), only about 20% of cadmium contained in NiCd batteries was recycled. This percentage of recycled NiCd batteries has gradually increased with the establishment of Rechargeable Battery Recycling Corp. in 1995. 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. 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 2003, secondary production in the United States amounted to about 400 metric tons (t). International Metals Reclamation Co. Inc. (Inmetco) in Ellwood City, PA, is the only cadmium recycling company in the United States. Although the plant was established 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. Detached cadmium plates then go directly into the furnace, using the High Temperature Metal Recovery (HTMR) process. Cadmium in smaller sealed batteries is recovered by burning off the castings and separators at a lower temperature than used in the HTMR process. The resulting 99.95% pure cadmium is shipped to battery manufacturers for reuse.

### **Chromium<sup>6</sup>**

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 scrap). Scrap from these sources is collected and sorted by grade (chemical composition) in scrap yards. Scrap brokers, collectors, and yards play a

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<sup>3</sup>Prepared by Larry D. Cunningham.

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

<sup>5</sup>Prepared by Josef Plachy.

<sup>6</sup>Prepared by John F. Papp.

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, 2004).

## Cobalt<sup>7</sup>

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, cobalt 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).

In 2003, scrap consumption reported by U.S. cobalt processors and consumers was 2,140 t of contained cobalt, 24% less than the 2,800 t consumed in 2002. U.S. imports of cobalt waste and scrap more than doubled to 482 t, gross weight, valued at \$4.0 million. Seven countries supplied 90% of this material—the United Kingdom (44%); Ireland (15%); Belgium (12%); Canada, France, and Germany (5% each); and Japan (4%). U.S. exports of cobalt waste and scrap nearly quadrupled to 405 t, gross weight, valued at \$2.6 million. Most of this material was sent to Canada (30%), the United Kingdom (17%), China and the Netherlands (13% each), Belgium (9%), Sweden (8%), and Japan and Switzerland (5% each).

## Columbium (Niobium)<sup>8</sup>

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; then it is effectively downgraded and 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 and superalloy producers for remelting. Detailed data on the quantities of columbium recycled were not available but may compose as much as 20% of U.S. columbium apparent consumption (Cunningham, 2004a).

## Copper<sup>9</sup>

According to revised data compiled by the International Copper Study Group (2004, p. 16-18), estimated world production of secondary refined copper in 2003 declined for the third consecutive year to 1.75 Mt, down from 2.13 Mt in 2000, and constituted only about 11.5% of global world refined copper production. With a notable exception for China, most of the major secondary producers had lower output. In China, secondary refined production rose by about 56,000 t (20%), largely on the strength of increased imports of copper and copper alloy scrap. 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.

Secondary refined production in the United States continued its downward trend, declining by 17,000 t (24%) in 2003. Secondary refined production has fallen by about 340,000 t since 1997 owing to contraction of the secondary smelting/refining industry. Copper recovered in alloys, chemicals, and powders from scrap (direct melt scrap) declined by about 70,000 t (7%), exceeding the overall decline in refined copper production (3%). At brass mills, the leading consumer of direct melt scrap, scrap consumption as a percentage of their total material supply (scrap plus refined copper) declined by about 2% to 59%.

Copper scrap prices generally followed the trend in refined copper prices. Limited domestic 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 1.2 cents per pound in 2003, down from 1.4 cents per pound in 2002 and 3.0 cents per pound in 2001. The average discount in December 2003 fell to less than 1.0 cents per pound. Similarly, the discount for refiners No. 2 scrap fell to 10.9 cents per pound in 2003 from 12.2 cents per pound and 13.7 cents per pound, respectively, in 2002 and 2001. This contradicted historical patterns where higher refined copper prices generally meant increased scrap discounts. COMEX refined copper prices fluctuated around \$0.75 per pound during the first half of the year before rising during the second half, reaching a monthly average of \$1.00 per pound in December, and an annual average of \$0.81 per pound, 13% higher than that for 2002.

Exports of copper scrap for 2003 totaled 689,000 t, up from 511,000 t in 2002. China (including Hong Kong) was the destination for 70% of domestic scrap exports and based on import data accounted for 63% of global scrap imports. The United States remained the leading source of scrap, accounting for 19% of global scrap trade (based on exports). This lent support to industry claims that

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<sup>7</sup>Prepared by Kim B. Shedd.

<sup>8</sup>Prepared by Larry D. Cunningham.

<sup>9</sup>Prepared by Daniel L. Edelstein.

aggressive buying by China exacerbated the tight supply of copper scrap available to U.S. consumers. Industry reports indicated that higher grades of scrap were increasingly going to China, which helped explain why the spread between refined copper prices and high-grade scrap remained very narrow despite the rise in refined copper prices (Platts Metals Week, 2003).

During 2003, three fire refineries processed scrap to recover unalloyed copper products in the United States. One of the refineries operated for only a portion of the year. Scrap was also consumed in relatively small quantities at several of the primary smelters. The last remaining U.S. secondary smelter closed in October 2001.

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 944,000 t of copper recovered from aluminum, copper, nickel, and zinc base scrap, brass mills recovered 71%; brass and bronze ingot makers, 10%; copper smelters and refiners, 6%; and miscellaneous manufacturers (including aluminum and steel alloy producers), foundries, and chemical plants, 13%. Alloyed copper products accounted for about 94% of the total copper recovered from scrap.

In 2003, copper recovered from refined or remelted scrap (about 78% from new scrap and 22% from old scrap) composed 30% of the total U.S. copper supply and had an equivalent refined value of \$1.77 billion. In 2003, following 5 years of decline, the conversion of old scrap to alloys and refined copper was essentially unchanged. Copper recovered from new scrap (738,000 t) declined by about 12%, and to a large extent was a reflection of reduced manufacturing levels. As evidence of continued weak U.S. demand for copper mill products, several major consumers of copper scrap announced cutbacks. During the first quarter, Olin Corporation closed its Indianapolis, IN, facility, citing that it had sufficient capacity to meet customer needs at other plants (Olin Corporation, 2003). Wolverine Tube, Inc. closed its Booneville, MS, facility, which produced both enhanced and smooth bore industrial tube for residential and commercial air conditioner manufacturers. Lackluster product demand and improved performance at its Jackson, TN, plant were cited by the company as reasons for closure (Wolverine Tube, Inc., 2003).

## Gallium<sup>10</sup>

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 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, 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§).

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.

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<sup>10</sup>Prepared by Deborah A. Kramer.

## Gold<sup>11</sup>

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. 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 60,000 kg and 47,000 kg, respectively, in 2003. These data, which were collected by the USGS, included 15,000 kg of old imported scrap. In 2003, U.S. exports of gold scrap increased by 85%, while imports increased by 26%. As it has been for many years, the United States was a net exporter of gold scrap in 2003. In 2003, the unit value of imported waste and scrap gold was \$276 per troy ounce, and exported, \$109 per ounce; the average price was \$365 per ounce (Platts Metals Week, 2004b).

## Indium<sup>12</sup>

Recycling of indium scrap continued to increase, but not enough to offset the decline in primary production.

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). Although there has been some interest in processing the material at this site for indium and other minerals, the priority was the clean up of the areas near the residential areas (U.S. Environmental Protection Agency, 2004§).

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 relatively short life cycle. Japan and other East Asian countries appear to be at the forefront of recycling efforts. Recent trends in indium prices combined with the curtailment of primary refining capacity have added an extra incentive to the recovery of secondary indium. Sustained high prices will encourage increased recycling and primary production (Metal-Pages, 2003§). Since indium is a byproduct of zinc, it is difficult to increase primary production unless there is an increase in zinc production. The languishing zinc market forced many high-cost and low-grade underground mines and a few of the older and less efficient zinc refineries to close. The price of zinc, however, was on the rise, and the production of indium was expected to increase also, but production is expected to remain below worldwide demand. There is some indium mineralization associated with tin and tungsten deposits but their economic potentials are difficult to determine because their complex mineralogy makes metallurgical recovery difficult and costly. The gap between world primary production and world consumption, estimated at 200 t, will most likely come from recycling as inventories were nearly exhausted by the end of 2003 (Platts Metals Week, 2004a). Currently 50% of consumed indium-tin oxide is from recycled sources, but could reach as high as 75% in 2004 (Roskill's Letter from Japan, 2004).

In the United States, only small amounts of new indium scrap were recycled in 2003. This is because 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 as the price of indium continues to increase.

## Iron and Steel<sup>13</sup>

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, 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 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 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 largest source is junked 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 (Rich Tavoletti, marketing manager, American Iron and Steel Institute, unpub. data, July 2002). Of the ferrous metals used to make a typical 2002 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

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<sup>11</sup>Prepared by Earle B. Amey.

<sup>12</sup>Prepared by Micheal W. George.

<sup>13</sup>Prepared by Michael D. Fenton.

2003—enough steel to produce more than 14 million new cars. The recycling rate of automobile scrap steel was 102.9% in 2003 compared with 100.6% in 2002. A recycling rate greater than 100% is a result of the steel industry recycling more steel from automobiles than was used in the domestic production of new vehicles.

Manufactured steel products have a wide range of physical and chemical characteristics according to relative contents of 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 (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 2003, BOFs were used to produce 49% of total steel in the United States, while using only 26% of total scrap consumed (American Iron and Steel Institute, 2003, p. 86). During the same period, EAFs produced 51% of total steel while using 72% of total scrap consumed. Scrap was also melted in blast furnaces and other types of furnaces.

During 2003, steel recycling rates were 103% for automobiles, 96% for construction structural beams and plates, 90% for appliances, 60% 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, 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 North America and Europe 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 (2003, p. 102), followed by Germany, Japan, Russia, the United Kingdom, France, Ukraine, and the Netherlands. The most significant importing nations were, in decreasing order of importance, China, the Republic of Korea, Belgium and Luxembourg, Spain, Germany, France, and Taiwan (International Iron and Steel Institute, 2003, p. 104).

The U.S. trade surplus for all classes of ferrous scrap was 7.2 Mt in 2003 (U.S. Census Bureau, unpub. data, 2003). Total U.S. exports of carbon steel and cast-iron scrap went to 64 countries and totaled 9.4 Mt. The largest tonnages went to China, the Republic of Korea, Mexico, and Canada. Total U.S. exports of stainless steel scrap went to 44 countries and consisted of 505,000 t. The largest tonnages went to Taiwan, the Republic of Korea, and Finland. U.S. exports of alloy steel scrap (excluding stainless steel) were shipped to 50 countries and consisted of 892,000 t. The largest tonnages went to China, Mexico, and Canada.

## Lead<sup>14</sup>

About 82% of the 1.40 Mt of refined lead produced in the United States in 2003 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-supplies. Lead-acid batteries account for 92% of lead produced from secondary sources, leaving only about 8% for all other sources, including building construction materials, cable covering, drosses and residues (new scrap) from primary smelter-refinery operations, and solder.

In 2003, there were 11 companies in the United States producing secondary lead, exclusive of that produced from copper-based scrap. Of the 1.14 Mt of lead recycled in 2003, 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 84% of the reported consumption of lead in the United States in 2003.

During 2003, the United States exported about 92,800 t of lead-bearing scrap, which included whole spent lead-acid batteries as well as nonbattery forms. Imported lead-bearing scrap in all forms totaled about 4,970 t during the year. The recovery of lead from spent lead-acid batteries and other lead scrap at secondary smelters in 2003 was sufficient to meet about 91% 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 2003, 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 2003 (American Metal Market, 2003). The average price for refined lead produced at secondary smelters in 2003 was about 45.3 cents per pound (Platts Metals Week, 2004b).

The demand for replacement automotive batteries was moderately stronger in 2003 than in 2002, but insufficient to counter the lower demand in the other battery sectors. Replacement battery demand is related principally to seasonal winter temperature extremes that increase the rate of automotive battery failures.

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<sup>14</sup>Prepared by Peter Gabby.

## Magnesium<sup>15</sup>

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 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).

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<sup>16</sup>

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 2003, 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 (677,000 t) and the average beverage can manganese content of 0.92% (Carlin, 2004; Plunkert, 2005). In the future, small additional amounts of manganese could be recovered through widespread recycling of dry-cell batteries (Watson, Andersen, and Holt, 1998).

## Mercury<sup>17</sup>

The mercury recycling industry is an important link between continued use of the metal and liability issues associated with mercury release and disposal into the environment, human health and mercury toxicity concerns, and increasing regulation of multisource mercury releases. If mercury-containing products are improperly recycled, then companies may face fines, prosecution, and long-term

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<sup>15</sup>Prepared by Deborah A. Kramer.

<sup>16</sup>Prepared by Lisa A. Corathers.

<sup>17</sup>Prepared by William E. Brooks.

liability. Local and State environmental regulations require adherence to the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as Superfund, to regulate generation, treatment, and disposal of products containing mercury (U.S. Environmental Protection Agency, undated a§, b§).

In 2003, as in previous years, mercury was recycled in-plant, as home scrap, to supply the chlorine-caustic soda industry, which continues to be the leading domestic end use for mercury in the United States. Approximately 3,000 t of mercury is contained in the domestic chlorine-caustic soda industry (Raloff, 2003§). Losses of mercury in the chlorine production process were initially as high as 200 grams of mercury per metric ton of chlorine output in the 1960s, but only 0.2 gram of mercury was reported lost per ton of chlorine produced today (Bunce and Hunt, 2003§). In 2000, for example, 86 t of mercury was used as replacement mercury for material lost in the manufacturing process (Arthur E. Dungan, Vice President, Chlorine Institute, written commun., June 3, 2003).

Commonly used mercury products include automobile convenience switches, dental amalgam, laboratory/medical devices including thermometers, fluorescent lamps, and thermostats. Mercury recycled from these sources is called old scrap. The overall use of mercury is declining and, even though mercury is recycled from these and other products, recycling of mercury from specific products varies. For example, only 20% to 23% of mercury-containing fluorescent lamps and 5% of mercury-containing thermostats are recycled (Abernathy, 2003; D.F. Goldsmith, President, D.F. Goldsmith Chemicals, oral commun., February 23, 2004); data on recycling rates for other materials are difficult to obtain.

The United States also receives some mercury from international sources, such as India, for recycling (Marley, 2003). However, through loopholes in legislation, some mercury-containing products may be landfilled without reclamation of the mercury and some material may be sent to Canada (Fortuna, 2004).

Mercury and mercury-containing products, such as fluorescent lamps, computers, and dental amalgam, are recycled by AERC Recycling and Bethlehem Apparatus Co. in Pennsylvania; D.F. Goldsmith Chemical and Metal Corp. in Illinois; Mercury Waste Solutions in Minnesota; and Onyx Environmental Services in Wisconsin. A list of more than 50 individuals and companies involved in mercury recycling is available from Mercury Recyclers (2002§), and a list of mercury recycling organizations is provided by Hospitals for a Healthy Environment (2004§) and the Ohio Office of Pollution Prevention (2004§).

## **Molybdenum<sup>18</sup>**

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<sup>19</sup>**

Austenitic stainless steel scrap is the largest source of secondary nickel for the United States, accounting for about 88% of the 93,400 t of nickel reclaimed in 2003. An additional 2% 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 (furnace dust, grindings, and mill scale). The remaining 10% 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.

Preliminary data from the International Nickel Study Group indicated that world demand for primary nickel in 2003 was a record high 1.23 Mt (International Nickel Study Group, 2004). Refinery production also increased—rising to 1.20 Mt from the alltime high of 1.18 Mt for 2002—but could not keep up with demand, creating a global deficit of about 30,000 t of primary nickel. This deficit, coupled with rising energy and refining costs, led to sharply higher prices for cut cathode and other forms of primary nickel.

World demand and prices for austenitic stainless steel scrap followed suit. For the third 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 was not expected to change in the near future because world demand for austenitic stainless steel was estimated to be growing at a rate of 3% to 6% per year (Hunter, 2002). World production of total stainless steel was about 22 Mt (gross weight) in 2003, up 7% from 2002 levels (Nijkerk, 2004). The overall scrap ratio for the Western World was expected to remain at 45% because of the constricted supply of scrap.

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<sup>18</sup>Prepared by Michael J. Magyar.

<sup>19</sup>Prepared by Peter H. Kuck.



Much of the growth in demand for stainless steel and nickel has occurred in East Asia. Consumption of primary nickel in China has been steadily rising during the past 5 years, going to 125.0 Mt in 2003 from 46.5 Mt in 1999. Japan and China were the leading consumers of stainless steel in 2003, followed by the United States. Russia has been exporting about 400,000 metric tons per year (t/yr) of stainless steel scrap, or about 34,000 t/yr of contained nickel, despite a 15% export duty on the material. In 2003, most of the Russian scrap went to stainless steel operations in Finland, Germany, and Sweden.

The United States produced 1.37 Mt (gross weight) of austenitic stainless steel in 2003, slightly greater than the 1.36 Mt in 2002. U.S. exports of stainless steel scrap rose to 37,800 t of contained nickel from 25,700 t in 2002, an increase of 47%. The increase in exports was driven by higher prices globally for ferrochromium, primary nickel, and key grades of stainless steel scrap. Taiwan was again the leading importing nation of U.S. stainless scrap, purchasing 9,630 t of contained nickel in 2003. The Republic of Korea was second with 6,360 t and was closely followed by China, with 6,210 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 2003. 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 5% 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 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<sup>20</sup>**

For most platinum-group metals (PGM) applications, the actual loss during use of the metal is small, and hence the ability to recover the metal efficiently 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. Spent automotive catalysts have emerged as a significant potential source of secondary palladium, platinum, and rhodium. In 2003, an estimated 13 t of platinum, 8 t of palladium, and 4 t of rhodium were available in the United States for recycling from autocatalysts.

### **Selenium<sup>21</sup>**

In 2003, 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.

As the price of selenium rose dramatically, the amount of recycling also increased. The USGS estimated that about 280 t/yr of secondary selenium was produced worldwide. This represented about 17% of refined selenium production coming from secondary sources.

In 2003, exports of selenium metal and waste and scrap increased by 181% compared with those of revised 2002, on a weight basis, from 87 t to 243 t. The Philippines was by far the leading market for selenium metal, scrap, and waste from the United States, accounting for almost 73% of these exports. Since the price of selenium was high, any inventories held by producers and consumers were exported to the Philippines, where they were then processed and exported to China (Mining Journal, 2004). Imports of selenium unwrought waste and scrap decreased by 13% to 367 t, compared with revised 2002 imports. The United States was a net importer of selenium in 2003 by 124 t (including the selenium content of SeO<sub>2</sub>) compared with 336 t in 2002.

### **Silver<sup>22</sup>**

About 1,600 t of silver, valued at \$300 million, was recovered from scrap in 2003. While the amount of silver recovered in 2003 was essentially unchanged from the amount recovered in 2002, the value increased substantially owing to a 32% increase in the average price of silver in 2003. Photographic scrap was estimated to have generated about 900 t of silver, most of which was recovered from spent fixer solution, x-ray and graphic arts wastes, and a small quantity directly from color film wastes. The remainder was recovered from jewelers' sweepings, spent catalysts, electronics scrap, and other heterogeneous silver bearing materials. Little or no increase in silver recycling in the United States can be attributed to the fact that scrap supply has declined, showing little response to the price increase within the range silver traded in during 2003. A price almost double the 2003 average of \$6.46 per troy ounce would be required to induce a significant surge in the volume of scrap. Also, thriftiness and substitution (product miniaturization, lower silver loadings, and substitution of nonprecious metals) reduced silver scrap supply in 2003. However, this was somewhat offset by more restrictive environmental regulations and the decommissioning of at least one ethylene oxide plant. Silver is

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<sup>20</sup>Prepared by Henry E. Hilliard.

<sup>21</sup>Prepared by Micheal W. George.

<sup>22</sup>Prepared by Henry E. Hilliard.

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 begun to show a decline owing to the inroad of digital photography.

### **Tantalum<sup>23</sup>**

In 2003, estimated overall U.S. apparent consumption of all tantalum materials was about 500 t, about the same as in 2002; 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, 2004b).

### **Tin<sup>24</sup>**

In 2003, 19% 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, three 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 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 2003 to 60% compared with 59% in 2002, 56% in 1995, and 15% in 1988 (Steel Recycling Institute, 2003).

### **Titanium<sup>25</sup>**

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. In the United States, titanium ingot producers (recyclers) included Allvac (Allegheny Technologies Inc.), Howmet Corp. (Alcoa Inc.), Lawrence Aviation Industries Inc., RMI Titanium Co. (RTI International Metals, Inc.), and Titanium Metals Corp.

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 2003, domestic producers of ferrotitanium were Global Titanium, Inc., Detroit MI; Galt Alloys Inc., North Canton, OH; and ShieldAlloy Inc., Newfield, NJ. Consumption by the steel industry was largely associated with the production of stainless steels. In the nonferrous metals industry, titanium scrap was primarily consumed to produce aluminum-titanium master alloys for the aluminum industry. When used in aluminum alloys, titanium improves casting and reduces cracking.

Consumption of scrap for the production of titanium ingot increased by 24% in 2003 compared with that of 2002. Compared with sponge, scrap supplied about 46% 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 2003, imports and exports of titanium scrap were evenly matched, with imports exceeding exports by only 237 t. Imports and exports of titanium scrap decreased 11% compared with those of 2002.

Owing to a drop in the supply of new scrap, the published price range for unprocessed titanium scrap turnings increased to between \$1.50 and \$1.70 per pound at yearend 2003 from between \$1.07 and \$1.10 per pound at yearend 2002. Yearend prices for ferrotitanium also significantly increased to between \$3.00 and \$3.20 per pound in 2003 from between \$2.16 and \$2.18 per pound in 2002.

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<sup>23</sup>Prepared by Larry D. Cunningham.

<sup>24</sup>Prepared by James F. Carlin, Jr.

<sup>25</sup>Prepared by Joseph Gambogi.

## Tungsten<sup>26</sup>

In 2003, an estimated 25% to 30% of world tungsten supply was from recycled materials (Maby, 2003, p. 5). Tungsten-bearing scrap originates during manufacture and/or after use in the following applications: catalysts for petroleum refining; 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 filaments and electrodes for lamps; and specialty alloys, such as superalloys and wear-resistant 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 are used to 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 2003, scrap consumption by U.S. tungsten processors and consumers contained 4,110 t of tungsten, which was a decrease of 6% from 4,380 t in 2002. The United States imported 1,120 t of tungsten contained in waste and scrap, valued at \$5.7 million, 24% more than the tungsten contained in waste and scrap imports in 2002. Nine countries supplied most of these imports—China, 18%; the United Kingdom, 12%; Israel and the Republic of Korea, 11% each; India, 10%; Japan, 8%; Germany, 7%; and Hong Kong and South Africa, 5% each. U.S. exports of tungsten waste and scrap nearly doubled to 702 t of contained tungsten valued at \$3.9 million. The leading destinations for these exports were China, 41%; India, 16%; Taiwan, 14%; Germany, 12%; the Netherlands, 5%; and Belgium, 4%.

## Vanadium<sup>27</sup>

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 is likely reused internally. Vanadium is also used as a catalyst; however, it is estimated that catalyst consumption accounts for less than 1% of the total U.S. vanadium consumption.

## Zinc<sup>28</sup>

In 2003, about 30% of the world's zinc production was from secondary materials—brass, die casting scrap, flue dust, galvanizing residues, and zinc sheet. In the United States, about one-fourth of the 1.4 Mt consumed by domestic industries is secondary zinc. About 85% of recycled zinc was derived from new scrap, generated mainly in galvanizing and die casting plants and brass mills. The remaining 15% was obtained from brass products, flue dust, old die casts, and old rolled zinc articles. Recycled zinc was used by 2 primary smelters and 12 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 are a changing number of smaller companies that usually produce pure zinc chemicals. IMCO Recycling Inc., Midwest Zinc Corp., and the 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 magnetic separation. 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 2003, trade in zinc scrap was small—about 3% of total domestic consumption. About 79% of imported zinc scrap was supplied by Canada, and the major destination of U.S. exports was China (73%), followed by India (20%), and Taiwan (3%). Prices for scrap varied according to quality, presence of other components, geographic location, and environmental difficulties in handling, transporting, or treating. The price for a ton of zinc metal contained in scrap was about three-fourths of the LME price for refined zinc metal.

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<sup>26</sup>Prepared by Kim B. Shedd.

<sup>27</sup>Prepared by Michael J. Magyar.

<sup>28</sup>Prepared by Jozef Plachy.

## Zirconium<sup>29</sup>

Zirconium scrap composes 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, vessels, and heat exchangers. Although no data are available as to the percentage breakdown of sources of scrap, 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 the two domestic zirconium 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. The scrap zirconium is blended with new zirconium metal produced from the processing of the zirconium silicate mineral, zircon.

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TABLE 1  
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS<sup>1</sup>

Year	Quantity of metal (metric tons)					Value of metal (thousands)			
	Recycled from new scrap <sup>2</sup>	Recycled from old scrap <sup>3</sup>	Recycled <sup>4</sup>	Apparent supply <sup>5</sup>	Percentage recycled	Recycled from new scrap <sup>2</sup>	Recycled from old scrap <sup>3</sup>	Recycled <sup>4</sup>	Apparent supply <sup>6</sup>
<b>Aluminum:</b> <sup>7</sup>									
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	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 <sup>r</sup>	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
<b>Chromium:</b> <sup>8</sup>									
1999	NA	NA	118,000	437,000 <sup>r</sup>	27 <sup>r</sup>	NA	NA	77,700	377,000 <sup>r</sup>
2000	NA	NA	139,000	589,000	24	NA	NA	98,600	423,000 <sup>r</sup>
2001	NA	NA	122,000	437,000 <sup>r</sup>	28 <sup>r</sup>	NA	NA	70,900	272,000 <sup>r</sup>
2002	NA	NA	137,000 <sup>r</sup>	481,000 <sup>r</sup>	29	NA	NA	75,000 <sup>r</sup>	284,000 <sup>r</sup>
2003	NA	NA	129,000	468,000	27	NA	NA	99,200	391,000
<b>Copper:</b> <sup>9</sup>									
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	358,000 <sup>r</sup>	1,310,000	4,050,000 <sup>r</sup>	32.5 <sup>r</sup>	1,860,000	697,000 <sup>r</sup>	2,550,000	7,860,000 <sup>r</sup>
2001	833,000	317,000 <sup>r</sup>	1,150,000	3,340,000 <sup>r</sup>	34.4 <sup>r</sup>	1,410,000	536,000 <sup>r</sup>	1,950,000	5,660,000 <sup>r</sup>
2002	842,000	208,000 <sup>r</sup>	1,050,000	3,450,000	30.4	1,410,000	348,000 <sup>r</sup>	1,760,000 <sup>r</sup>	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
<b>Iron and steel:</b> <sup>10</sup>									
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	60	NA	NA	5,320,000	8,880,000
2002 <sup>11</sup>	NA	NA	69,000,000	119,000,000	58	NA	NA	6,390,000	10,200,000
2003 <sup>11</sup>	NA	NA	61,300,000	117,000,000	52	NA	NA	10,500,000	25,000,000
<b>Lead:</b> <sup>12</sup>									
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	1,090,000	1,700,000	64.1	45,500	1,000,000	1,050,000	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
2003	33,900	1,100,000	1,140,000	1,430,000	79.7	32,700	1,060,000	1,100,000	1,380,000
<b>Magnesium:</b> <sup>13</sup>									
1999	52,000	34,200	86,100	224,000 <sup>r</sup>	38 <sup>r</sup>	178,000	117,000	294,000	766,000 <sup>r</sup>
2000	52,200	30,100	82,300	199,000 <sup>r</sup>	41 <sup>r</sup>	158,000	90,800	248,000	601,000 <sup>r</sup>
2001	38,600	27,200	65,800	151,000 <sup>r</sup>	44 <sup>r</sup>	106,000	75,000	181,000	416,000 <sup>r</sup>
2002	47,100	26,400	73,600	148,000 <sup>r</sup>	50 <sup>r</sup>	126,000	70,500	196,000	395,000 <sup>r</sup>
2003	44,700	25,100	69,800	152,000	46	107,000	60,200	168,000	366,000
<b>Nickel:</b> <sup>14</sup>									
1999	NA	NA	71,000	211,000	34	NA	NA	427,000	1,270,000
2000	NA	NA	84,000	231,000	36	NA	NA	725,000	1,990,000 <sup>r</sup>
2001	NA	NA	102,000 <sup>r</sup>	230,000	44	NA	NA	604,000 <sup>r</sup>	1,370,000
2002	NA	NA	106,000 <sup>r</sup>	227,000 <sup>r</sup>	47 <sup>r</sup>	NA	NA	720,000 <sup>r</sup>	1,540,000 <sup>r</sup>
2003	NA	NA	93,400	211,000	44	NA	NA	899,000	2,030,000
<b>Tin:</b> <sup>15</sup>									
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	6,700	13,900	46,300	30	24,400 <sup>r</sup>	29,900 <sup>r</sup>	54,300 <sup>r</sup>	316,000 <sup>r</sup>
2002 <sup>r</sup>	3,790	6,760	10,600	49,100	22	18,400	40,600	59,000	307,000
2003	2,460	5,420	7,880	40,900	19	NA	NA	NA	NA
<b>Titanium:</b> <sup>16</sup>									
1999	NA	NA	21,900	W	55	NA	NA	28,900 <sup>e</sup>	NA
2000	NA	NA	18,500	W	50	NA	NA	38,200 <sup>e</sup>	NA
2001	NA	NA	17,000	W	39	NA	NA	35,200 <sup>e</sup>	NA
2002	NA	NA	11,600	W	40	NA	NA	25,600 <sup>e</sup>	NA
2003	NA	NA	14,300	W	46	NA	NA	48,000 <sup>e</sup>	NA

See footnotes at end of table.

TABLE 1--Continued  
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS<sup>1</sup>

Year	Quantity of metal (metric tons)					Value of metal (thousands)			
	Recycled from new scrap <sup>2</sup>	Recycled from old scrap <sup>3</sup>	Recycled <sup>4</sup>	Apparent supply <sup>5</sup>	Percentage recycled	Recycled from new scrap <sup>2</sup>	Recycled from old scrap <sup>3</sup>	Recycled <sup>4</sup>	Apparent supply <sup>6</sup>
Zinc: <sup>17</sup>									
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 <sup>r</sup>	317,000	57,000	375,000	1,420,000	26.4	307,000	55,200	362,000	1,380,000 <sup>r</sup>
2002	319,000	47,300	366,000	1,420,000 <sup>r</sup>	25.8 <sup>r</sup>	272,000	40,300	312,000	1,210,000 <sup>r</sup>
2003	295,000	50,300	345,000	1,340,000	25.8	264,000	45,100	309,000	1,200,000

<sup>6</sup>Estimated. <sup>r</sup>Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

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

<sup>2</sup>Scrap 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.

<sup>3</sup>Scrap that results from consumer products.

<sup>4</sup>Metal recovered from new plus old scrap.

<sup>5</sup>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.

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

<sup>7</sup>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.

<sup>8</sup>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.

<sup>9</sup>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.

<sup>10</sup>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.

<sup>11</sup>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 was \$172 per metric ton. Steel production unit value based on HTS 7206 and 7207 was \$259 per ton.

<sup>12</sup>Lead 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.

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

<sup>14</sup>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 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.

<sup>15</sup>Monetary value based on Platts Metals Week composite price for tin.

<sup>16</sup>Percentage recycled based on titanium scrap consumed divided by primary sponge and scrap consumption.

<sup>17</sup>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<sup>1</sup>

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)	
<b>Aluminum:</b>						
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
2003	577,000	NA	633,000	440,000	NA	496,000
<b>Chromium:<sup>2</sup></b>						
1999 <sup>r</sup>	262,000	46,500	168,000	75,200	20,300	84,300
2000 <sup>r</sup>	469,000	80,800	323,000	66,100	19,500	94,900
2001 <sup>r</sup>	439,000	75,600	281,000	50,500	15,400	74,100
2002	343,000	59,000 <sup>r</sup>	259,000 <sup>r</sup>	88,500 <sup>r</sup>	21,200 <sup>r</sup>	92,200 <sup>r</sup>
2003	505,000	86,700	394,000	97,700	23,700	115,000
<b>Copper:<sup>3</sup></b>						
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
2003	689,000	558,000	664,000	90,600	70,700	124,000
<b>Iron and steel:</b>						
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
2003	10,900,000	10,900,000	1,960,000	3,690,000	3,690,000	556,000
<b>Lead:</b>						
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	10,000 <sup>r</sup>	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
<b>Magnesium:</b>						
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
2003	5,040	5,040	11,800	16,200	16,200	22,000
<b>Nickel:<sup>4</sup></b>						
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
2003	1,410,000	50,900	704,000	230,000	12,000	138,000
<b>Tin:</b>						
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
2003	5,040	5,040	8,630	921	921	686
<b>Titanium:</b>						
1999	8,130	8,130	11,700	6,870	6,870	19,500
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

See footnotes at end of table.



TABLE 2--Continued  
 SALIENT U.S. RECYCLING TRADE STATISTICS FOR SELECTED METALS<sup>1</sup>

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)	
<b>Zinc:</b>						
1999	23,500 <sup>r</sup>	NA	\$18,600 <sup>r</sup>	26,600	NA	\$13,100
2000	21,900 <sup>r</sup>	NA	12,800 <sup>r</sup>	36,500 <sup>r</sup>	NA	16,200
2001	26,800 <sup>r</sup>	NA	14,200 <sup>r</sup>	39,300	NA	11,600
2002	19,800 <sup>r</sup>	NA	11,200 <sup>r</sup>	31,200	NA	9,530
2003	32,300	NA	23,300	10,300	NA	5,740

<sup>r</sup>Revised. NA Not available.

<sup>1</sup>Contained weight based upon 100% of gross, unless otherwise specified.

<sup>2</sup>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.

<sup>3</sup>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%.

<sup>4</sup>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.