RECYCLING—METALS

Introduction[1]

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

Recycling, a significant factor in the supply of many of the metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of waste, and reduced emissions associated with energy savings. Table 1 shows salient U.S. apparent supply and recycling statistics for selected metals. Apparent metal supply of 152 million metric tons (Mt) was valued at $44.0 billion in 2000. By weight, iron and steel accounted for 88.0% of apparent supply. By value, aluminum accounted for 36.0% of apparent supply and iron and steel accounted for 29.2%. Recycling contributed 80.7 Mt of metal, valued at about $18.2 billion, or over one-half of metal apparent supply by weight.

This report summarizes metal recycling. The U.S. Geological Survey publishes separate annual reviews for each of the metals summarized in this report; those reviews contain more detailed information about individual metals and recycling of those metals.

Primary indicates material from ore deposits; 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—plates, sheets, bars, rods, etc.—new scrap is generated in the form of cuttings, trimmings, and off-specification materials. When these shapes are converted to parts, new scrap is generated in the form of turnings, stampings, cuttings, and off-specification materials. Similarly, when parts are assembled into products, new scrap is generated. Once a product completes its useful product life, it becomes old scrap. Used beverage cans and junked automobiles are examples of old consumer scrap; used jet engine blades and vanes are an example of old industrial scrap. A wide variety of descriptive terms including home scrap, mill scrap, purchased scrap, prompt scrap, etc. have evolved to describe scrap generated by a wide variety of industry practices.

Aluminum[2]

Various forms of aluminum scrap are recovered by almost every segment of the domestic aluminum industry. Integrated primary aluminum companies, independent secondary smelters, fabricators, foundries, and chemical producers are known to recover aluminum from scrap. Integrated primary aluminum companies and independent secondary smelters, however, are the major consumers of scrap.

The independent secondary aluminum smelters consume scrap and produce alloys for the diecasting industry. A cursory look at the distribution of these smelters in the United States reveals a heavy concentration of smelters in the automotive and appliance manufacturing areas of the country.

The other major consumers of aluminum scrap are the integrated aluminum companies. The integrated companies frequently purchase scrap from their industrial customers directly or on a contract-conversion basis. Major integrated aluminum companies also operate can recycling programs and have established thousands of collection centers around the country for used aluminum beverage cans.

Used beverage can (UBC) scrap is the major component of processed old aluminum scrap, accounting for approximately one-half of the old scrap consumed in the United States. Most UBC scrap is recovered as aluminum sheet and manufactured into aluminum beverage cans. Most of the other types of old scrap are recovered in the form of alloys used by the diecasting industry; the bulk of these die casts is used by the automotive industry.

Aluminum recovered from purchased scrap decreased by 7% in 2000 compared with that of 1999. Of the 3.45 Mt of recovered metal, 60% came from new (manufacturing) scrap, and 40%, from old (discarded aluminum products) scrap.

According to figures released by the Aluminum Association Inc., the Can Manufacturers Institute, and the Institute of Scrap Recycling Industries, Inc., 62.6 billion aluminum UBCs were recycled in the United States in 2000, for a beverage can recycling rate of 62.1% or nearly 2 of every 3 aluminum cans shipped. Although the recycling rate was slightly lower than the 1999 rate of 62.5%, this was the 12th consecutive year that the U.S. recycling rate exceeded 60%. According to the organizations, the average aluminum beverage can produced domestically is comprised of more than 51% recycled content (Aluminum Association Inc., 2001).

Purchase prices for aluminum scrap, as quoted by American Metal Market, fluctuated during the year but closed at lower 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, 47.5 to 48.5 cents per pound; old sheet and cast aluminum, 38.5 to 39.5 cents per pound; and clean, dry aluminum turnings, 40 to 41 cents per pound.

Aluminum producers' buying price range for processed and delivered UBCs, as quoted by American Metal Market, also closed lower at yearend. The price range began the year at 57 to 59 cents per pound and closed the year at 53 to 54 cents per pound. Resource Recycling published a monthly transaction price for aluminum UBCs in its Container Recycling Report. During the year, the monthly average decreased significantly

[1]Prepared by John F. Papp [Telephone: (703) 648-4963; Fax: (703) 648-7757].
[2]Prepared by Patricia A. Plunkert (703) 648-4979; Fax (703) 648-7757.

from 62.9 cents per pound in January to 53.9 cents per pound in December. However, the annual average price for aluminum UBCs in 2000 of 57.7 cents per pound was higher than the 1999 annual average of 50.6 cents per pound.

The yearend indicator prices for selected secondary aluminum ingots, as published in American Metal Market, also decreased significantly compared with those of 1999. The closing prices for 2000 were as follows: alloy 380 (1% zinc content), 68.7 cents per pound; alloy 360 (0.6% copper content), 74.1 cents per pound; alloy 413 (0.6% copper content), 73.8 cents per pound; and alloy 319, 72.7 cents per pound. Platt's Metals Week published an annual average U.S. price of 65.6 cents per pound for A-380 alloy (3% zinc content). The average annual London Metal Exchange (LME) cash price for a similar 380 alloy was 55.2 cents per pound.

Beryllium[3]

Beryllium is used in many applications where such properties as light weight and stiffness are important. In 2000, the United States, one of only three countries that processed beryllium ores and concentrates into beryllium products, supplied most of the rest of the world with these products.

Beryllium-copper alloys, most of which contain approximately 2% beryllium, are used in a wide variety of applications and account for the largest share of annual U.S. apparent consumption on a beryllium-metal-equivalent basis. Beryllium metal is used principally in aerospace and defense applications, and beryllium oxide serves mainly as a substrate for high-density electronic circuits. Because of its high cost, beryllium use is restricted to those applications in which its properties are crucial. Such substitutes as graphite composites, phosphor bronze, steel, and titanium are available for certain beryllium applications but with a substantial loss in performance.

In 2000, U.S. apparent consumption of beryllium totaled about 300 metric tons. Unknown quantities of new scrap generated in the processing of beryllium metal and beryllium-copper alloys were recycled. The new scrap generated during the machining and fabrication of beryllium metal and alloys was returned to the metal-alloy producers for recycling. The beryllium in beryllium-copper fabricated parts was so widely dispersed in products, and so highly diluted when those products were recycled, that it was essentially dissipated. Additionally, small quantities of obsolete military equipment containing beryllium were recycled (Cunningham, 2001a; Petkof, 1985).

Cadmium[4]

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 firm figures on the amounts of cadmium recovered from sources such as electroplating waste, filter cakes, sludges, and other cadmium-containing wastes. The total amount of secondary cadmium, estimated by the International Cadmium Association, was about 10% of 2000 world primary production.

Recycling of cadmium is a young but growing industry spurred by environmental concerns and regulatory moves to limit dissipation of cadmium 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. 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 concentration and, therefore, are difficult to recycle for cadmium. Consequently, much of this cadmium is dissipated.

In 2000, the annual rate of secondary production in the United States amounted to about 200 t. The 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 process (HTMR). 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.

The future of cadmium recycling, and of cadmium industry in general, could be profoundly affected by a proposed ban of cadmium use in Europe by the European Commission. According to the European Union's Directive 2000/60/EC on water, the ban on Ni-Cd batteries is to start in 2008, if approved by the European Parliament.

Chromium[5]

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

Scrap is generated during the manufacturing process (new scrap) and as a result of recycling obsolete equipment (old scrap). Scrap from these sources is collected and sorted by grade (i.e., chemical composition) in scrap yards. Scrap brokers play a role in moving material from where it is recovered to where it is consumed. The steel industry consumes stainless

[3]Prepared by Larry D. Cunningham (703) 648-4977; Fax (703) 648-7757.
[4]Prepared by Jozef Plachy (703) 648-4982; Fax (703) 648-7757.
[5]Prepared by John F. Papp (703) 648-4963; Fax (703) 648-7757.

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).

Cobalt[6]

Cobalt-bearing scrap is generated during manufacture and/or following use in these 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.

In 2000, scrap consumption reported by U.S. cobalt processors and consumers was 2,550 t of contained cobalt, a decrease of 6% from the 2,720 t consumed in 1999. U.S. imports of cobalt waste and scrap increased by 41% to 550 t, gross weight, valued at $4.1 million. Seven countries supplied more than 90% of these materials—the United Kingdom (43%), France (13%), Germany (11%), Canada (10%), Japan (6%), and Argentina and Belgium (5% each). U.S. exports of cobalt waste and scrap are reported in combination with exports of unwrought cobalt metal and metal powders.

Copper[7]

According to data compiled by the International Copper Study Group (International Copper Study Group, 2001, p. 16), estimated world production of secondary refined copper increased by about 3% in 2000 to 2.1 Mt and accounted for 14.2% of global world refined copper production. According to data compiled by the World Bureau of Metal Statistics (World Bureau of Metal Statistics, 2001, p. 42) and adjusted by the U.S. Geological Survey, an additional 3.13 Mt of copper was recovered from the direct remelting of copper scrap, a decline of about 60,000 t from that of 1999 revised data. Secondary refined production in the United States continued its downward trend, declining by more than 20,000 t (9%) in 2000, based on revised data. Secondary refined production has fallen by about 190,000 t (47%) since 1997 owing to contraction of the secondary smelting/refining industry. Copper recovered in alloys and chemicals (direct melt scrap) was essentially unchanged at 1.10 Mt.

Copper scrap prices generally followed the trend in refined copper prices, though the discount for various grades of scrap tended to narrow with lower prices. Despite growing global inventories, copper prices in January continued the upward trend begun in mid-1999, and rose to their highest level in almost 2 years. The COMEX spot price averaged $0.85 per pound in January. However, prices weakened beginning in March, the COMEX price averaging only $0.80 in the March to June period. In response to declining global inventories, the average monthly COMEX price climbed to $0.91 in September. Prices weakened and fluctuated during the fourth quarter of the year, the COMEX price averaging $0.86 and finishing the year at $0.85. The average annual COMEX price of $0.84 was at its highest level since 1997. While the discount to COMEX prices for No. 1 (brass mill) scrap and No. 2 (refiners) scrap averaged 3.3 cents per pound and 19.0 cents per pound, respectively, for the year, margins narrowed to below 3 cents and 17.5 cents per pound during the period of low copper prices at midyear and rose to 4.6 cents and 19 cents, respectively, during December.

According to data compiled by the International Copper Study Group (2001, p. 40-43), global trade in copper scrap increased significantly in 2000, principally owing to increased shipments from the United States, which rose from 315,000 t (estimated copper content 258,000 t) to 485,000 t (estimated copper content 395,000 t). The United States was the largest international source for copper scrap, accounting for about 17% of all reported scrap exports. China (including Hong Kong), which reported copper scrap receipts of 2.6 Mt, up from 1.8 Mt in 1999, was the largest recipient of scrap, accounting for about 54% of reported global scrap imports. It was also the largest recipient of U.S. scrap, accounting for 46% of all scrap exports. Data on world scrap trade are incomplete, however, with reported imports generally exceeding reported exports. In the case of China, it is believed that import data may include some very low-grade or misclassified material. In 2000, U.S. imports of copper scrap of 112,000 t were essentially unchanged. Canada and Mexico were the leading sources for U.S. imports of copper and copper alloy scrap, accounting for 79% of imports in 2000.

During 2000, two secondary smelters and three fire refineries processed scrap to recover unalloyed copper products in the United States. Scrap was also consumed in relatively small quantities at several of the primary smelters. One fire refinery in Missouri, Warrenton Refining Company, which had closed in 1999, reopened under new ownership.

In May, Southwire Company closed its secondary smelter and associated electrolytic refinery, in Carrollton, GA. Southwire continued to operate its rod mill housed within its Copper Division Southwire (CDS). Sixteen months prior, as part of a restructuring plan aimed at lowering its costs, Southwire had unsuccessfully placed its Carrollton copper smelter/refinery operations on the market. Southwire cited economic factors, including the continued cost of compliance with environmental regulations in the metro-Atlanta area, for the closure of copper smelting operations. CDS was constructed in 1972, at a time when primary producers exerted greater control over copper prices. As part of the closure justification, Southwire cited the advent of worldwide commodity prices and their own “strong buying position” as leverage in meeting future raw material needs (Southwire Company, 2000). Southwire processed a mixture of imported blister and copper scrap at its smelter to produce anode for electrolytic refining. Southwire, which had a capacity to produce 140,000 tons per year (t/yr), of refined copper, was one of two remaining secondary smelters in the United States, two other smelters having closed in the preceding 3 years. Southwire closed its other secondary copper smelter in Gaston, SC, at the end of 1994, also citing the high cost of

[6]Prepared by Kim B. Shedd (703) 648-4974; Fax (703) 648-7757.
[7]Prepared by Daniel L. Edelstein (703) 648-4978; Fax (703) 648-7757.

environmental compliance as the reason for closure.

Direct melt scrap, principally alloy scrap, was consumed at about 35 brass mills, 20 alloy ingot makers, and 500 foundries, chemical plants, and miscellaneous consumers. Of the total copper recovered from copper-, aluminum-, nickel-, and zinc-base scrap, copper smelters and refiners recovered 16%; brass mills, 64%; brass and bronze ingot makers, 9%; and miscellaneous manufacturers (including aluminum and steel alloy producers), foundries, and chemical plants, 11%. Alloyed copper products accounted for about 83% of the total copper recovered from scrap.

In 2000, copper recovered from all refined or remelted scrap (about 28% from old scrap and 72% from new scrap) composed 32% of the total U.S. copper supply and had an equivalent refined value of $2.6 billion. Despite a slight decline in copper recovery from scrap, the equivalent refined value of copper recovered from scrap rose by about 15% in 2000 owing to higher average copper prices. Copper recovered from old scrap continued its 3-year decline, falling 5% to 363,000 t and was down by 27% from that recovered in 1997. Copper recovered from new scrap increased nominally to 952,000 t, reflecting an overall increase in brass mill shipments to the domestic market.

Gallium[8]

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. Also, there is some GaAs that remains in the reactor after the ingot is produced, which may be recycled. During the wafer preparation and polishing stages, significant quantities of wastes are generated. Before wafers are sliced from the ingot, both ends of the ingot are cut off and discarded, because impurities are concentrated at the tail end of the ingot, and crystal imperfections occur at the seed 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 may 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 water, silicone oils, waxes, plastics, and glass (Kramer, 1998, 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, 1998, 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, 1998, p. 15).

Gold[9]

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

A considerable quantity of scrap is generated during manufacturing, but because of tight controls over waste materials in precious metals plants, nearly all of this "home-generated" scrap can be recovered. Probably the greatest loss in gold fabrication takes place in gold-plating plants where fouled or depleted solutions are sometimes discarded. Some old scrap, however, is lost because, in practice, gold cannot be economically recovered from all manufactured products.

Gold-bearing scrap is purchased on the basis of gold content, as determined by analytical testing and the market price for gold on the day that the refined product is available for sale. Processing charges and adjustments for processing losses are deducted from the total value in settling payments. Aside from dealer-processors and refiners, scrap gold has no market. The Federal Trade Commission requirement for karat identification of jewelry alloys requires gold refiners to identify the chemical analysis of the alloys they purchase and to separate the constituents of scrap to assure meeting karat standards [Public Law 226, An act forbidding the importation, exportation, or carriage in interstate commerce of falsely or spuriously stamped articles of merchandise made of gold or silver or their alloys, and for other purposes, 1906, 59th Congress, 1st Session, Revised Statute U.S. v. 34, part 1, June 13, p. 260].

Refiners throughout the world recover secondary gold from

[8]Prepared by Deborah A. Kramer (703) 648-7719; Fax (703) 648-7722.

[9]Prepared by Earle B. Amey (703) 648-4969; Fax (703) 648-7757.

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

Domestic consumption of new and old gold scrap was 42,000 kg and 70,000 kg respectively. These data were collected in 2000 by the U.S. Geological Survey (USGS), and include 30,000 kg of old imported scrap. In 2000, U.S. exports of gold scrap increased, after 2 years of decrease, while imports stayed at their highest level since 1995. As it has been for many years, the United States was a net exporter of gold scrap in 2000.

Prices for gold waste and scrap imported and exported in 2000 averaged $74 and $226 per troy ounce, respectively; at the same time, the average price for gold was $280 per ounce (Platts Metals Week, 2001).

Indium[10]

Domestic recovery of secondary indium remained low for the 4th year since the unusually high level of 1996, when high prices encouraged the recycling of more old scrap. In 2000, as is typical in the United States, most of the secondary indium was recovered from new scrap. The actual quantity of secondary indium recovered is not known, but it was small; only in 1996 was the quantity significant following a $12 per troy ounce price increase in 1995 that resulted from concern over supply. In 1996, recycling provided much of domestic supply (Fineberg, 1996), and imports decreased more than 50%.

In Japan, however, recycling has maintained its importance in recent years (McColloch, 2000). In 2000, indium demand reached a record 335 t in 2000 in Japan, with slightly more than one-half of the material coming from recycled scrap (Roskill's Letter from Japan, 2001).

Iron and Steel[11]

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 used and obsolete iron and steel products, and the ferrous scrap generated in steel mills and steel-product manufacturing plants. The North American steel industry's overall recycling rate is nearly 64% (Steel Recycling Institute, A few facts about steel—North America's #1 recycled material, Fact Sheet, accessed August 23, 2001, at URL http://www.recycle-steel.org/fact).

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 post-consumer scrap is also available for recycling. The largest source is junked automobiles, followed by demolished steel structures, wornout 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, Recycling scrapped automobiles, accessed August 23, 2001, at URL http://www.recycle-steel.org/cars/autorec.html). Of the ferrous metal used to make a typical 2000 U.S. family vehicle, about 44% was recycled metal. About 12,000 car dismantlers and 3,000 scrap processors produced more than 14 Mt of iron and steel scrap from about 14 million automobiles for recycling in 2000—enough steel to produce 48 million steel utility poles, which are one-third of the utility polls in the United States (Steel Recycling Institute, Recycling scrapped automobiles, accessed August 23, 2001, at URL http://www.recycle-steel.org/cars/autorec.html).

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 1999, BOFs were used to produce 53% of total steel in the United States while using only 28% of total scrap

[10]Prepared by Robert D. Brown, Jr. (703) 648-4984; Fax (703) 648-7757.
[11]Prepared by Michael D. Fenton (703) 648-4972; Fax (703) 648-7757.

consumed (American Iron and Steel Institute, 2000, p. 86). During the same period, EAFs produced 47% of total steel while using 71% of total scrap consumed. Scrap was also melted in blast furnaces and other types of furnaces.

Iron and steel scrap is an additional resource for steelmakers that is more than just economically beneficial. Recycling conserves natural resources, energy, and landfill space. Recovery of 1 t of steel from scrap conserves an estimated 1,030 kg of iron ore, 580 kg of coal, and 50 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, Recycling Scrapped Automobiles, accessed July 17, 2000, at URL http://www.recycle-steel.org/cars/autorec.html).

During 1999, steel recycling rates were 95% for automobiles, 95% for construction structural beams and plates, 84% for appliances, 58% for steel cans, and nearly 64% overall (Steel Recycling Institute, A few facts about steel—North America's #1 recycled material, Fact Sheet, accessed August 23, 2001, at URL http://www.recycle-steel.org/fact).

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 not the leading exporting country of iron and steel scrap in 1999, as reported by the International Iron and Steel Institute (2000, p. 102). Germany took the lead, followed by Russia, the United States, Ukraine, Japan, France, the United Kingdom, and the Netherlands. The four most significant importing nations were, in decreasing order of importance, Turkey, the Republic of Korea, and the United States (International Iron and Steel Institute, 2000, p. 104).

The U.S. trade surplus for all classes of ferrous scrap was 2.2 Mt in 2000 (U.S. Census Bureau, unpub. data, 2000). Total U.S. exports of carbon steel and cast-iron scrap went to 55 countries and totaled 4.5 Mt. The largest tonnages went to the Republic of Korea, Canada, Mexico, China, and Taiwan. Total U.S. exports of stainless steel scrap went to 43 countries and consisted of 470,000 t. The largest tonnages went to the Republic of Korea, Taiwan, Canada, and Japan. U.S. exports of alloy steel scrap (excluding stainless steel) were shipped to 46 countries and consisted of 815,000 t. The largest tonnages went to Canada and Mexico.

Lead[12]

About 77% of the 1.46 Mt of refined lead produced in the United States in 2000 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 uninterruptible power-supply equipment, load-leveling equipment for commercial electrical power systems, industrial forklifts, mining vehicles, golf cars and other human and materials transport vehicles, lawn equipment, airport ground-support equipment, floor sweepers and scrubbers, and bicycles. About 5% of the recycled lead was recovered from other lead-based sources including solder, cable covering, building construction materials, and drosses and residues (new scrap) from primary smelter-refinery operations.

Recycled lead was produced domestically by 18 companies operating 26 lead recovery plants. Of the 1.12 Mt of lead recycled in 2000, about 98% 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 87% of the reported consumption of lead in the United States in 2000.

During the period 1996 to 2000, the United States exported an average of about 92,000 t/yr of lead-bearing scrap, including battery as well as nonbattery forms. Only minimal quantities of lead-bearing scrap were imported during this period. The spot price for smelters' heavy soft lead scrap averaged about 21 cents per pound during this period. The average North American Producer price for refined lead was about 45 cents per pound.

During 2000, the recovery of lead from spent lead-acid batteries and other lead scrap at secondary smelters was sufficient to meet about 76% of the demand for lead in the manufacture of new batteries. The market price for whole scrap batteries averaged about 5.5 cents per pound near the end of 2000, translating to a lead price of 11 cents per pound, assuming that lead accounted for about 50% of battery weight. The failure rate of automotive batteries remained fairly level during most of the year, as sustained temperature extremes were absent in the more heavily populated regions of the United States. In December, however, extreme winter conditions in many parts of the United States increased the level of automotive battery failures, but the usual associated increase in demand for lead by the battery manufacturers was tempered by the high level of inventories of new replacement batteries held by the manufacturers. Production of lead at secondary smelters increased by about 2% compared with production in 1999. Stocks of refined secondary lead held by producers and battery manufacturers increased appreciably at yearend.

In January, Johnson Controls, Inc., Milwaukee, WI, signed new tolling agreements to recover lead from spent lead-acid batteries for its battery business on the west coast of the United States. Reportedly, the processing of the spent battery units was to be divided between the secondary smelter plants of RSR Corp. at City of Industry, CA, and GNB Technologies, Inc. at Vernon, CA. The tolling agreements were expected to be in effect for 1 year (Ryan's Notes, 2000a).

Exide Corp., Reading, PA, closed its Laureldale, PA, battery manufacturing plant at the end of June. According to company officials, the action was taken as a consolidation measure, thus achieving higher capacity utilization at its remaining battery manufacturing plants (Ryan's Notes, 2000b).

In late September, Exide Corp. completed its acquisition of GNB Technologies, Inc., Atlanta, GA. As a result of the purchase, and following shareholder approval, Exide Corp. was renamed Exide Technologies. GNB had supplied a significant portion of the industrial batteries used in the North American

[12]Prepared by Gerald R. Smith (703) 648-4983; Fax (703) 648-7757.

market. Thus, the purchase allowed Exide to reenter the North American industrial battery business. GNB also was a leading supplier of automotive batteries for both the original equipment and replacement battery markets. Following the acquisition, Exide also announced several initiatives designed to restructure the newly formed company: consolidation of automotive battery manufacturing facilities in the United States; consolidation of industrial battery operations in Europe; closure of several distribution centers and branch locations by the end of 2000; and downsizing and relocation of new headquarters to Princeton, NJ, from Reading, PA (Exide Technologies, 2000).

In December, Exide Technologies, Princeton, NJ, reported plans to reopen and upgrade its battery manufacturing plant in Maple, Ontario. Exide expected to produce industrial-type lead-acid batteries at the plant for the growing motive power and telecommunications markets. One type of battery to be produced at the Maple plant is used as a back-up power source for Internet and wireless driven voice, data, and multimedia networks. The company had closed the Maple plant, originally used to manufacture automotive-type lead-acid batteries, after Exide's acquisition of GNB Technologies, Inc. Exide's investment in the plant will extend over a 12-month period with initial production expected early in 2001 and full production by yearend (Platt's Metals Week, 2000).

Magnesium[13]

New magnesium-base scrap typically is categorized into one of four types. Type I is high-grade scrap, generally material such as gates, runners, and drippings from diecasting operations that is uncontaminated with oils. Types II, III, and IV are lower graded materials. Type II is oil-contaminated scrap, type III is dross from magnesium-processing operations, and type IV is chips and fines. The most desirable type of scrap is type I. Most of the type I scrap is generated during diecasting magnesium alloys. This scrap is either reprocessed at the diecasting 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 consists, in descending order of importance, primarily of 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 separate 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 any alloying elements are added, such as aluminum, manganese, or zinc, 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[14]

Scrap recovery specifically for manganese is insignificant. To a large extent, it is recycled incidentally as a minor component within scrap of another metal, 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, contains about 0.7% manganese (Jones, 1994, p. 10). Manganese that is recycled to steelmaking within steel scrap largely is lost because of its removal in the decarburization step of steelmaking, but needs to be added back. Manganese is recycled in the aluminum industry as a component of scrap of certain manganese-bearing aluminum alloys, principally as UBC in which the manganese content is about 1%. Melting and processing of aluminum is nonoxidizing toward manganese, so that most of the manganese is retained. The amount of manganese being recycled in the aluminum industry is estimated to be in the vicinity of 1% of manganese apparent consumption. In the future, small additional amounts of manganese could be recovered through widespread recycling of dry cell batteries

[13]Prepared by Deborah A. Kramer (703) 648-7719; Fax (703) 648-7722.

[14]Prepared by Thomas S. Jones (703) 648-4973; Fax (703) 648-7757.

(Watson, Andersen, and Holt, 1998).

Mercury[15]

In response to health and environmental concerns, secondary mercury is recovered from a variety of source materials as mandated by Federal and State regulations to reduce the discharge and disposal of mercury-containing products. Electronic devices including rectifiers, switches, thermostats, and relays; dental amalgams; batteries; and other instruments such as thermometers, are processed to recover any contained mercury. However, the largest source of secondary mercury remains the spent catalysts used in the production of chlorine and caustic soda. Three companies, one each in Illinois, Minnesota, and Pennsylvania, produce the bulk of secondary mercury in the United States. Mercury waste generated in the manufacturing of products (new scrap) is either reused internally or collected for reprocessing.

Molybdenum[16]

Catalysts containing about 3,400 t of molybdenum were recycled. The U.S. superalloys producers consumed about 460 t of pure molybdenum metal scrap. Also molybdenum contained in alloy iron and steel scrap was recycled to produce new alloyed steel products. The amount of molybdenum consumed to produce these products was not recorded.

Nickel[17]

Austenitic stainless steel scrap is the largest source of secondary nickel for the United States, accounting for about 83% of the 84,000 t of nickel reclaimed in 2000. An additional 2% came from the recycling of alloy steel scrap. The combined 85% represents not only scrap used in raw steel production, but also lesser amounts of scrap consumed by steel and iron foundries, as well as nickel reclaimed from stainless steelmaking residues (e.g., furnace dust, grindings, and mill scale).

Western World demand for austenitic scrap increased substantially in the first half of 2000 because of higher prices for primary nickel. The price rise and global scrap drawdown were the result of a shortage of cathode and briquets. In the second half of 2000, recessionary forces in the United States triggered a dropoff in domestic stainless steel production and a slackening of deliveries of austenitic scrap to U.S. steelworks. The U.S. steel industry produced a near-record 1.24 Mt, gross weight, of austenitic stainless steel in 2000 despite the second half dropoff. Production of austenitic stainless steel in the European Union (EU) and Japan rose to 3-year highs, spurring international trade in austenitic scrap (Hunter, 2001).

Demand in the Western World for primary nickel was estimated to be a record 1.029 Mt in 2000, up slightly from 1.004 Mt in 1999 (International Nickel Study Group, 2001a, p. 3-12). The Western World supply of primary nickel also increased, but lagged behind demand for the second consecutive year (see Nickel chapter). A shortage of cathode and briquets caused prices to rise at the beginning of 2000. The monthly LME cash price for 99.8% pure nickel peaked at $10,280 per metric ton in March and then gradually declined during the remainder of the year to finish at $7,314 per metric ton. The gradual price decline was attributed to the buildup of recessionary forces in the United States and parts of East Asia. Prices for austenitic scrap in Pittsburgh closely tracked the LME price and also gradually declined during the last half of the year.

Russia and the United States continued to be the largest exporters of stainless steel scrap. The huge influx into Western Europe of Russian stainless steel scrap and nickel alloy scrap, which began in 1995, slackened in the first half of 1999 after the Russian Government imposed a new tariff on scrap metal exports. Nickel and six other scrap metals were subject to the 20% export tariff (Reuters Limited, 2000a, b). In November 1999, the tariff was raised to 30% (Interfax International Ltd., 2000a). Because of the tariff and low prices for cathode at the time, Russian exports of stainless steel scrap fell 9% between 1998 and 1999, dropping from 343,000 t (gross weight) to 313,000 t (International Nickel Study Group, 2001b, p. 79). Russian scrap exports recovered in the second half of 1999 in response to higher nickel prices and continued to rise throughout 2000. (See Figure 1.) At yearend 2000, nickel in scrap was being quoted in Europe at 84% of the LME cash price. Discounts in the United States were greater than those in Europe, with U.S. scrap prices equivalent to about 77% of LME nickel values. Discounts began 2000 on both continents at 88%.

The Russian Government extended its 5% export tariff on refined nickel into 2000 and later raised it to 10%. The new tariffs and regulations left nonferrous scrap brokers in a more precarious position than the primary producers. In March 2000, the Russian Ministry of Economics proposed raising the 30% tariff on scrap to 50%—to curb excessive exports (Interfax International Ltd., 2000b; Reuters Limited, 2000a, b). Federation officials also were evaluating new procedures for levying value-added taxes on exports. The entire policy of levying tariffs on exports was debated in the Federal Council, the upper house of the Russian Parliament.

Inmetco converts a variety of nickel and chromium wastes at Ellwood City, PA, into a remelt alloy suitable for stainless steelmaking. The Ellwood City operation was set up in 1978 to reclaim chromium and nickel from emission control dusts, swarf, grindings, mill scale, and other wastes generated by the stainless steel industry. Over the past 22 years, Inmetco has made a number of improvements to its Pennsylvania facility and now also processes nickel- and/or chromium-bearing filter cakes, plating solutions and sludges, catalysts, refractory brick, and spent batteries.

ELG Haniel GmbH handled about 1.2 Mt of stainless steel scrap worldwide in 1999, up 9% from that of 1998. About 790,000 t was sold to steelworks in Germany and other EU member countries. The company moved the scrap processing facilities of Jewometaal, its Dutch subsidiary, to a new location in the Port of Rotterdam. Jewometaal spent Eur 8 million, or about $7.7 million, on the new recycling and transshipment facilities (ELG Haniel GmbH, 2000, p. 32-33).

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 10% of the nickel reclaimed in 2000. Scrap in this category comes from a myriad of sources and includes cupronickel (a series of copper

[15]Prepared by Robert G. Reese, Jr. (703) 648-4981; Fax (703) 648-7757.
[16]Prepared by John W. Blossom (703) 648-4964; Fax (703) 648-7757.
[17]Prepared by Peter H. Kuck (703) 648-4965; Fax (703) 648-7757.

alloys containing 2% to 45% Ni), the Monels (a group of alloys typically containing 65% Ni and 32% Cu), nickel-silver (a misnomer for a series of copper-zinc-nickel alloys), and nickel-aluminum bronze. Cupronickel is stronger and more resistant to oxidation at high temperatures than pure copper, making it desirable for saltwater piping and heat exchanger tubes. Nickel-silver—a white brass—is used for rivets, screws, camera parts, and optical equipment. The aerospace industry uses 2218, 2618, 4032, 8280 and several other wrought aluminum alloys that contain 0.2% to 2.3% nickel.

The remaining 8% of reclaimed nickel came from pure nickel scrap and nickel-base alloy scrap. Superalloy producers and downstream fabricators of turbine engines and chemical processing equipment generate a large part of this material—some of which is sent to scrap processors for salvaging and cleaning and later returned to the producers for remelting. However, because of the stringent specifications for INCONEL 718, WASPALOY, and similar aerospace-grade superalloys, much of the superalloy scrap is not suitable for direct recycling and is sold to stainless steel producers, steel foundries, or specialty alloy casting companies. Significant amounts of superalloy scrap are intentionally generated during the forging and machining of turbine parts for aircraft engines. As little as 1 out of 7 kg of superalloy may end up in a finished turbine part (Lane, 1998). Superalloy scrap is an important source of revenue for most aerospace machine shops. Proper segregation of turnings and grindings, on-site recovery of cutting fluids, and timely shipping of the scrap can make the difference between profitability and bankruptcy for a small- to medium-size machine shop. Inclusion of a pea-size piece of a lead, bismuth, or tungsten alloy can put an entire truckload of superalloy scrap out of specification. Aircraft engine repair facilities are an important source of obsolete superalloy scrap.

Demand for superalloy scrap reached record levels in 2000. Three factors contributed to the tightness of supply. First, manufacturing of land-based gas turbines increased dramatically as power companies rushed to meet growing demand for electrical power, especially on the West Coast of the United States. Second, orders for new jet aircraft engines and other aerospace components picked up after a 2-year downturn. Third, several processors of superalloy scrap were operating at maximum capacity. Low prices for primary nickel in 1998 and 1999 had discouraged the scrap industry from adding new processing capacity in 2000. A major problem was inadequate capacity to process turnings from machine shops. Turnings are one of the larger sources of superalloy scrap, but require considerable processing. Scrap processors must crush, sample, clean, densify, and package the turnings before they can be shipped to the buyer (Newman, 2001).

To help relieve the tightness in the superalloy scrap market, Keywell LLC set up a new processing facility in Los Angeles, CA, in early 2000. The Los Angeles facility became operational in the second half of 2000 and has begun consolidating shipments for forwarding to Keywell's Vac Air Alloys Division at Frewsburg, NY. The Frewsburg facility reportedly is the largest processor of vacuum-grade superalloy and titanium scrap in the world. In March, Keywell also opened a new facility in Fairless Hills, PA, to process stainless steel scrap in bulk.

Superalloy scrap processors now have to compete with stainless steel blenders and nickel-cobalt refineries for the scrap. The ongoing expansion of the Airbus consortium is expected to increase superalloy arisings in Western Europe. To date, superalloy melters have shied away from Russian aerospace scrap. Traditional Russian aerospace grades are difficult to blend with Western alloys because of differences in chemical composition. These problems may disappear as Russia begins producing more Western-equivalent grades of superalloys.

The U.S. collection and recycling program for nickel-cadmium (NiCd) and nickel-metal hydride (NiMH) batteries is in a period of rapid expansion. Federal legislation passed in 1996 has helped spur the program. The program is administered by the Rechargeable Battery Recycling Corporation (RBRC), a nonprofit public service corporation funded by more than 285 manufacturers and marketers of portable rechargeable batteries and battery-operated products (Millard, 1999). The program is primarily designed to recycle the more than 75 million small, sealed, rechargeable NiCd batteries sold annually to U.S. and Canadian businesses and consumers for use in cordless products. RBRC licensees now account for four out of five NiCd sales in North America. Almost 25,000 retail outlets or community collection sites in the United States accept spent NiCd batteries. Some 4,500 collection sites in Canada also participate in the RBRC program. The bulk of the collected batteries are sent to Inmetco for reclamation.

In Western Europe, the portable battery market grew from 2.8 billion units in 1985 to almost 4.9 billion units in 1995, an increase of 70%. This increase has led to renewed concerns in the EU about the inclusion of NiCd batteries in municipal waste going to landfills or incinerators. About 62% of the municipal waste in the EU is currently landfilled; another 19% is incinerated. In March 2001, the European Commission drafted a directive that calls for the phase out of cadmium in portable batteries by January 1, 2008. Special exemptions were proposed for batteries used in medical devices, emergency equipment, and special scientific instrumentation. The proposed directive also would establish a minimum recycling target of 55% for all collected batteries. More costly NiMH and lithium-ion batteries would be substituted for the NiCds. Some 13,000 t of portable NiCd batteries averaging 15% cadmium (Cd) and 3,500 to 4,000 t of industrial NiCd batteries averaging 6% Cd are marketed annually in the EU. Industry studies show that only 11% of the portable NiCd batteries were being reclaimed compared with 53% of the industrial batteries (Commission of the European Communities, 2001).

A proposal by the U.S. Department of Energy (DOE) to decontaminate 6,000 t of radioactively contaminated nickel was opposed by a large part of the metals industry. The House Committee on Commerce also expressed its concerns to DOE. The Metals Industry Recycling Coalition has taken the position that no metal originating from Nuclear Regulatory Commission (NRC)-licensed fuel cycle and DOE-operated facilities should be released for unrestricted recycling or reuse even if the levels of radioactivity are within "safe" levels specified by the NRC. The Steel Manufacturers Association took legal action to delay an NRC rule that would have allowed the material to be decontaminated and recycled back to the public. Other coalition members included the Specialty Steel Industry of North America, the American Iron and Steel Institute, the Nickel Development Institute, and the Copper and Brass Fabricators Council (Kelly, 1999).

Platinum-Group Metals[18]

Despite their limited availability, platinum-group metals (PGM), and chemical compounds containing them, are widely used as catalysts in the chemical and petroleum industries as well as used in electrical conductors, extrusion devices, dental and medical prostheses, and jewelry. Since 1998, platinum has been used in the manufacture of computer hard disks. Moreover, since the beginning of the 1975 model year, new automobiles sold in the United States have been equipped with PGM-based (primarily platinum) catalytic converters to remove polluting substances from engine exhausts.

For most 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, e.g., from the glass industry. Spent automotive catalysts have emerged as the leading source of secondary PGM. The United States has the world's most developed network for recycling spent autocatalysts; most domestic scrap yards systematically remove catalytic converters from scrapped vehicles. Although smaller vehicle dismantlers have considered it uneconomical to collect the catalysts, the rise in PGM prices prompted many of them to begin removing catalytic converters for the first time in 2000. This development led to an increase in the amount of platinum recovered—from about 9,800 kg in 1999 to about 10,900 kg in 2000. In recent years, palladium catalysts have become more widely used in catalytic converters for motor vehicles. An estimated 4,700 kg of palladium was recovered in 2000.

Selenium[19]

Most selenium, except that applied to the surfaces of the photoreceptor drums in plain paper copiers, is dissipated as process waste or is eventually sent to a landfill as a minor constituent of a used product. The small quantities that are added to glass as a decolorant and to ferrous and nonferrous metal alloys to improve metalworking properties are not recovered in the recycling of those materials and are probably volatilized during remelting. Selenium rectifiers, once a major source of old scrap, generally have been replaced by silicon rectifiers. Additionally, current high processing costs have made it uneconomical to recover selenium from the scrapped rectifiers that are available.

In 2000, no secondary selenium was recovered in the United States. Wornout photoreceptor drums and scrap generated in the manufacture of new drums were exported for the recovery of the selenium content. An estimated 50 t of secondary selenium was imported; this was about 10% of all selenium imports. Practically all the selenium used in photoreceptor drums is recovered through very efficient recycling programs (Hoffman and King, 1997, p. 704). Secondary selenium was recovered in Canada, Europe, Japan, and the Philippines. The photocopier market for selenium, still the main feed source for secondary selenium, continued its decline owing to competition from other technologies, mainly organic photoreceptors.

Hydromet Environmental Recovery Ltd. will accept waste material for the recovery of selenium and tin at its new plant scheduled to open during 2001 in Newman, IL. The plant expects to process selenium materials from the copper refining and photocopy industries (American Metal Market, 2000b).

Silver[20]

About 1,680 t of silver, valued at $270 million, was recovered from scrap in 2000. Photographic scrap was estimated to have generated 1,300 t of silver; the largest part 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, electronic scrap, and other heterogeneous silver bearing materials. Recovered silver accounted for about one-fourth of industrial demand in 2000.

Tantalum[21]

Tantalum is ductile, easily fabricated, highly resistant to corrosion by acids, and a good conductor of heat and electricity and has a high melting point. The major use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. More than 60% of total tantalum consumed is in the electronics industry. Major end uses for tantalum capacitors include portable telephones, pagers, personal computers, and automotive electronics. Alloyed with other metals, tantalum is also used in making carbide tools for metalworking equipment and in the production of superalloys for jet engine components. Substitutes such 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 2000, U.S. apparent consumption of tantalum totaled about 650 t, with consumed scrap (from various sources) accounting for an estimated 20% of the total. Recycling of tantalum, mostly from new scrap, takes place largely within the processing and end-product industries. In addition, quantities of tantalum are recycled in the form of used tantalum-bearing cutting tools and high-temperature alloy melting scrap. Tantalum recycled from finished electronic components (old scrap) is very small and not yet fully developed. However, new scrap materials reclaimed at manufacturing plants that produce tantalum-related electronic components are a major source of tantalum supply and are delivered back to tantalum processors for recycling (Cunningham, 1985, 2001b; Tantalum-Niobium International Study Center, 1996).

Tin[22]

In 2000, about 30% of the domestic apparent supply of tin metal was recovered from scrap (table 1). Old tin scrap is collected at hundreds of domestic scrap yards, five detinning plants, and most municipal collection-recycling centers. New tin scrap is generated mainly in the tin mills of six steel plants,

[18]Prepared by Henry E. Hilliard (703) 648-4970; Fax (703) 648-7757.
[19]Prepared by Robert D. Brown, Jr. (703) 648-4984; Fax (703) 648-7757.
[20]Prepared by Henry E. Hilliard (703) 648-4970; Fax (703) 648-7757.
[21]Prepared by Larry D. Cunningham (703) 648-4977; Fax (703) 648-7757.
[22]Prepared by James F. Carlin, Jr. (703) 648-4985; Fax (703) 648-7757

scores of canmaking facilities, numerous brass and bronze plants, and many soldermaking operations. Most tin-scrap-processing facilities are close to the tin-using industries and to densely populated markets in the Midwest and the Northeast.

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, solder, etc.); the tin is recycled within its own product-line industries and thus reappears in regenerated alloys.

The Steel Recycling Institute (SRI) continued to promote the recycling of used tin cans, which has become an important raw material for the nation's steel industry during the past 15 years. SRI announced that the domestic steel can recycling rate had remained about the same in 2000 as in 1999 at 58%, compared with 56% in 1998, and 15% in 1988 (Steel Recycling Institute, 2001).

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

Titanium[23]

Titanium scrap is primarily used as an alternative to titanium sponge in the production of titanium ingot. Common forms of titanium scrap include turnings and bulk weldables (bars, billet cutoffs, plate trimmings, etc.). Titanium scrap is generated during the melting, forging, casting, and fabrication of titanium components. "New scrap" is generated during the production and fabrication of titanium components, while "old scrap" is recovered from used components (old aircraft parts, heat exchangers, submarine hulls, etc.).

Currently, over one-half of the titanium feedstock for ingot production is derived from scrap. Scrap is recycled into titanium ingot with or without virgin metal by using either vacuum-arc-reduction or cold-hearth melting practices. Titanium ingot producers in France, Germany, Japan, Russia, the United Kingdom, and the United States lead the recycling of titanium scrap. In the United States, titanium ingot producers (recyclers) included Allegheny Technologies Inc., Howmet International, Lawrence Aviation Industries Inc., RMI Titanium Co., and Titanium Metals Corp. Numerous companies were involved in the generation, segregation, and processing of scrap for recycling.

In 2000, U.S. production of titanium ingot decreased 3% compared with that of 1999. Scrap supplied about 50% of the titanium required for ingot production, somewhat less than the 55% supplied in 1999. Although no data are available as to the percentage breakdown of sources of titanium scrap, less than 2% of titanium ingot production is estimated to be derived from old scrap.

Although consumption of titanium metal by commercial aircraft producers remained relatively high from an historical perspective, recycling of titanium scrap decreased by about 9% compared with that of 1999. While imports of titanium scrap increased 9% compared with those of 1999, exports decreased 38%. In contrast to 1999, the United States was a net exporter of titanium scrap in 2000, with exports exceeding imports by 2,490 t.

In addition to that recycled by ingot producers, titanium scrap is consumed by the steel and nonferrous alloy industries. It should be noted that imports and exports of titanium scrap include material to be recycled back into titanium components and that consumed by steel and nonferrous alloys.

Consumption by the steel industry is largely associated with the production of stainless steels and is used for deoxidation, grain-size control, and carbon and nitrogen control and stabilization. In steelmaking, titanium is introduced as a ladle addition normally in the form of ferrotitanium because ferrotitanium has a lower melting point and has a higher density than scrap. Ferrotitanium is produced from titanium and steel scrap by induction melting.

World ferrotitanium production capacity is estimated to be 64,000 t, led by, in descending capacity order, the United Kingdom, Russia, Japan, and the United States. In 2000, there were three domestic producers of ferrotitanium: Global Titanium, Inc., Detroit MI; Galt Alloys Inc., North Canton, OH; and ShieldAlloy Inc., Newfield, NJ. In addition to domestic producers, numerous companies are involved in the import and trade of ferrotitanium.

In the nonferrous metals industry, titanium scrap is primarily consumed to produce aluminum-titanium master alloys for the aluminum industry. When used in aluminum alloys, titanium improves casting and reduces cracking.

Owing to a moderate drop in demand, prices for unprocessed titanium scrap turnings (Ti-6AL-4V) decreased from about $1.10 per pound at yearend 1999 to $0.78 per pound at yearend 2000. Yearend prices for ferrotitanium prices decreased from about $2.40 per pound in 1999 to $1.59 per pound in 2000.

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

Tungsten[24]

In 2000, an estimated 25% to 30% of world tungsten supply was from recycled materials (Maby, 1999, p. 4). Tungsten-bearing scrap originates during manufacture and/or after use in the following applications: cemented carbides used for cutting and wear-resistant applications; mill products made from metal powder, such as filaments and electrodes for lamps and heavy metal alloys; and alloys, such as tool steels, high-speed steels, and superalloys. 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

[23]Prepared by Joseph Gambogi (703) 648-7718; Fax (703) 648-7722.

[24]Prepared by Kim B. Shedd (703) 648-4974; Fax (703) 648-7757.

substitute for tungsten concentrate by tungsten processors (Smith, 1994, p. 4-14).

Cemented carbide scrap is recycled by several processes. Some of these processes result in tungsten carbide powder combined 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 2000, scrap consumption reported by U.S. tungsten processors and consumers was 5,120 t of contained tungsten, an increase of 3% from the 4,980 t (revised) consumed in 1999. The United States imported 993 t of tungsten contained in waste and scrap, valued at \$6.2 million, 31% less than the tungsten content of waste and scrap imports in 1999. Five countries supplied 70% of these imports—China, 25%; the Republic of Korea and Russia, 15% each; Germany, 8%; and Japan, 7%. U.S. exports of tungsten waste and scrap were an estimated 827 t of contained tungsten valued at \$4.4 million, which was approximately equal to the estimated tungsten content of waste and scrap exports in 1999. The leading destinations for these exports were Germany, 48%; Taiwan, 10%; China, 7%; Canada; 6%; and Belgium, 5%.

Vanadium[25]

Vanadium is used primarily as an alloying element. Very small quantities of vanadium, often less than 1%, are alloyed with other metals to produce various ferrous and nonferrous alloys. Owing to the relatively small amount of vanadium involved, these alloys in general do not lend themselves to recycling for vanadium recovery. Vanadium is also used as a catalyst. It is estimated that catalyst consumption accounts for less than 1% of the total U.S. vanadium consumption. However, processing spent vanadium catalysts accounts for the only significant source of refined secondary vanadium. Three plants in Arkansas, Louisiana, and Texas accounted for most of the recycled vanadium catalyst. Any new scrap generated in either the production of alloys or catalysts is likely reused internally.

Zinc[26]

In 2000, about 30% of world's zinc production was produced from secondary materials—brass, die casting scrap, flue dust, galvanizing residues, zinc sheet, etc. In the United States, more than one-fourth of the 1.61 Mt consumed by domestic industries is secondary zinc. More than three-quarters of recycled zinc was derived from new scrap generated mainly in galvanizing and die casting plants and brass mills. The remaining one-quarter was obtained from brass products, flue dust, old die casts, and old rolled zinc articles. Recycled zinc was used by 3 primary smelters and 12 large and medium (more than 1,000 t/yr) sized secondary smelters primarily for production of zinc chemicals, mainly oxide, and zinc metal, including alloys. In addition, there is a changing number of smaller companies that usually produce zinc chemicals. IMCO Recycling Inc., Midwest Zinc Corp., and the Zinc Corporation of America are the largest U.S. recyclers of 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 2000, trade in zinc scrap was small—about 2% of total domestic consumption. Nearly 93% of imported zinc scrap was supplied by Canada, and the major destination of U.S. exports was Taiwan (51%). 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.

Zirconium[27]

Zirconium scrap comprises about one-fourth to one-third of the feedstock for ingot production. New scrap is generated during the melting, forging, rolling, casting, and fabrication of zirconium components. In addition, some obsolete or old scrap is recycled from dismantled process equipment, vessels, heat exchangers, etc. 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 ingot producers, Wah Chang, a subsidiary of Allegheny-Teledyne Corporation, Albany, OR, and Western Zirconium, a subsidiary of Westinghouse Electric Company, Ogden, UT, using vacuum-arc-reduction melting practices.

References Cited

Aluminum Association Inc., 2001, Americans recycle 2 of 3 aluminum cans: Washington, DC, Aluminum Association Inc. press release, April 19, 4 p.
American Iron and Steel Institute, 2000, Annual report 2000: American Iron and Steel Institute, August, 130 p.
American Metal Market, 2000a, DLA taps two for electronic scrap contracts: American Metal Market, v. 107, no. 53, March 16, p. 8.
———2000b, Hydromet ready to take waste for metal recovery operations: American Metal Market, v. 108, no. 243, December 19, p. 10.

[25]Prepared by Robert G. Reese, Jr. (703) 648-4981; Fax (703) 648-7757.
[26]Prepared by Jozef Plachy (703) 648-4982; Fax (703) 648-7757.
[27]Prepared by James B. Hedrick (703) 648-7725; Fax (703) 648-7722.

Commission of the European Communities, 2001, European Parliament and Council directive on batteries and accumulators (draft): Brussels, Commission of the European Communities, March 30, 53 p.
Cunningham, L.D., 1985, Tantalum, *in* Mineral Facts and Problems: U.S. Bureau of Mines Bulletin 675, p. 811-822.
———2001a, Beryllium: U.S. Geological Survey Mineral Commodity Summaries 2001, p. 30-31.
———2001b, Tantalum: U.S. Geological Survey Mineral Commodity Summaries 2001, p. 164-165.
Dahm, M.R., 2000, Preparation of secondary magnesium for use in hot metal desulfurization, *in* Stewart, D.L., Jr., Stephens, R.L., and Daley, J.C., eds., International Symposium—Recycling of Metals and Engineered Materials, 4th, Pittsburgh, PA, October 22-25, 2000, Proceedings: Warrendale, PA, Minerals, Metals, & Materials Society, p. 1333-1340.
ELG Haniel GmbH, 2000, Annual report—1999: Duisburg, Germany, ELG Haniel GmbH, January, 74 p.
Exide Technologies, 2000, Exide completes acquisition of GNB Technologies: Reading, PA, Exide Technologies news release, September 29, 4 p.
Fineberg, Seth, 1996, Indium can't find bottom; growth in recycling: American Metal Market, v. 104, no. 201, October 16, p. 1.
Hoffman, J.E., and King, M.G., 1997, Selenium and selenium compounds, *in* Kirk-Othmer encyclopedia of chemical technology, (4th ed., v. 21): New York, John Wiley & Sons, p. 686-719.
Hunter, B.A., 2001, The globalized picture of stainless steel scrap: 2001 Annual Meeting of the International Nickel Study Group, The Hague, The Netherlands, April 25-27, Handout, 11 p.
Interfax International Ltd., 2000a, Economics Ministry wants to raise export duties on nonferrous scrap: Interfax International Ltd., Mining and Metals Report, v. 9, no. 13 (418), March 24-30, p. 21.
———2000b, Russia to raise export duties on nonferrous scrap to 50%: Interfax International Ltd., Mining and Metals Report, v. 9, no. 33 (438), August 11-17, p. 3.
International Copper Study Group, 2001, Copper Bulletin: Lisbon, International Copper Study Group, v. 8, no. 9, 48 p.
International Iron and Steel Institute, 2000, Steel statistical yearbook 2000: International Iron and Steel Institute, December, 111 p.
International Nickel Study Group, 2001a, World nickel statistics—Monthly bulletin: The Hague, the Netherlands, International Nickel Study Group, v. 11, no. 9, September, 80 p.
———2001b, World nickel statistics—Monthly bulletin (Special issue): The Hague, the Netherlands, International Nickel Study Group, v. 11, no. 11, November, 87 p.
Jones, T.S., 1994, Manganese material flow patterns: U.S. Bureau of Mines Information Circular 9399, 57 p.
Kelly, N.E., 1999, SMA leads coalition against radioactive scrap, *in* Steel Mini-mills supplement: American Metal Market, v. 107, no. 231, December 2, p. 6A.
Kieffer, B.F., 1982, Recycling systems with particular reference to the zinc process, *in* Tungsten—1982: International Tungsten Industry Association, San Francisco, CA, June 1-5, Proceedings, p. 102-114.
Kramer, D.A., 1988, Gallium and gallium arsenide—Supply, technology, and uses: U.S. Bureau of Mines Information Circular, 25 p.
Lane, John, 1998, Recycling of superalloys for gas turbines *in* Superalloys for gas turbines, Tampa, FL, June 15-17, 1998, Proceedings: Gorham, ME, Gorham Advanced Materials Inc., 7 p.
Maby, Michael, 1999, Market report by the Secretary-General, *in* Tungsten—Advanced technology & new applications: International Tungsten Symposium, 8th, Fukuoka, Japan, October 12-15, 1999, Transcripts of Papers, 15 p.
McColloch, Russ, 2000, Indium displays a bright future: Metal Bulletin Monthly, no. 357, September, p. 55-57.
Millard, Ralph, 1999, RBRC Ni-Cd recycling program update, *in* Battery Waste Management—Past, Present and Future, 11th International Seminar and Exhibit, Deerfield Beach, FL, November 1-3, 1999, Proceedings: Boca Raton, FL, Florida Educational Seminars, Inc., 16 unpaginated view graphs.
Newman, E.J., 2001, Superalloy scrap demand reaching record levels: American Metal Market, Superalloys Supplement, v. 109, no. 166, August 27, p. 11.
Papp, J.F., 1991, Chromium, nickel, and other alloying elements in U.S.-produced stainless and heat-resisting steel: U.S. Bureau of Mines Information Circular 9275, 41 p.
Petkof, Benjamin, 1985, Beryllium, *in* Mineral Facts and Problems: U.S. Bureau of Mines Bulletin 675, p. 75-82.
Platt's Metals Week, 2000, Exide to reopen battery plant: Platt's Metals Week, v. 71, no. 51, December 18, p. 14.
Platts Metals Week, 2001, Platt's Metals Week annual metal averages for 2000: Platts Metals Week, v. 72, no. 6, February 5, p. 18.
Reuters Limited, 2000a, No big change seen in Russian duties: Reuters Limited, April 4, 2 p.
———2000b, Russian stainless exports on upswing?: Reuters Limited, February 9, 1 p.
Roskill's Letter from Japan, 2001, Indium—Record Japanese demand in 2000: Roskill's Letter from Japan, no. 296, April, p. 10, 11.
Ryan's Notes, 2000a, JCI's new west coast tolling contracts: Ryan's Notes, v. 6, no. 2, January 10, p. 4.
———2000b, Lead and zinc—Exide to close Laureldale SLI plant: Ryan's Notes, v. 6, no. 10, March 6, p. 3.
Smith, G.R., 1994, Materials flow of tungsten in the United States: U.S. Bureau of Mines Information Circular 9388, 23 p.
Southwire Company, 2000, Southwire to close copper refinery and sell aluminum smelter: Carrollton, GA, Southwire Company news release, April 4, 2 p.
Steel Recycling Institute, 2001, Steel recycling rate continues moderate ascent: Pittsburgh, PA, Steel Recycling Institute news release, April 10, 2 p.
Tantalum-Niobium International Study Center, 1996: Tantalum-Niobium International Study Center, no. 86, June, p. 1-11.
Watson, N.J., Andersen, R.W., and Holt, G., 1998, Battery recycling in the metals industry from Europe to the USA, *in* International Seminar on Battery Waste Management, 10th, Deerfield Beach, FL, October 26-28, 1998, Proceedings: Boca Raton, FL, Florida Educational Seminars Inc., unpaginated.
Wentz, Harold, and Ganim, Larry, 1992, Recycling—The catchword of the 90's—Recycling of magnesium: Light Metal Age, v. 50, nos. 1 and 2, February, p. 14-21.
World Metal Statistics, 2001, World Bureau of Metal Statistics, London: World Metal Statistics, v. 54, no. 8, p. 42.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Mineral Commodity Summaries, annual.
Mineral Industry Surveys, monthly and annual.
Minerals Yearbook, annual.
United States Mineral Resources, Professional Paper 820, 1973.

Other

Aluminum Association Inc. Aluminum Statistical Review, annual.
Aluminum Metal Monitor (monthly report of Commodities Research Unit Ltd. (CRU)).
American Bureau of Metal Statistics (ABMS) Non-Ferrous Metal Data.
American Metal Market, daily.
Battery Council International, special reports.
Brass and Bronze Ingotmakers Association.
Copper and Brass Fabricators Council, Inc.
Institute of Scrap Recycling Industries.
Lead and Zinc Statistics (monthly bulletin of the International Lead and Zinc Study Group).
Metal Bulletin (London).
Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
Platts Metals Week.
Resource Recycling.
Roskill Information Services Ltd. Zinc 1997, 6th Ed.
U.S. Department of Commerce News.

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/	Percent recycled	Recycled from new scrap 2/	Recycled from old scrap 3/	Recycled 4/	Apparent supply 6/
Aluminum: 7/									
1996	1,730,000	1,570,000	3,310,000	8,340,000	40	$2,730,000	$2,480,000	$5,200,000	$13,100,000
1997	2,020,000	1,530,000	3,550,000	8,740,000	41	3,430,000	2,590,000	6,020,000	14,800,000
1998	1,950,000	1,500,000	3,440,000	9,040,000	38	2,810,000	2,160,000	4,970,000	13,100,000
1999 r/	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
Chromium: 8/									
1996	NA	NA	98,400	468,000 r/	21.0 r/	NA	NA	96,000 r/	651,000 r/
1997	NA	NA	120,000	489,000 r/	24.5	NA	NA	122,000 r/	716,000 r/
1998	NA	NA	104,000	524,000 r/	19.8 r/	NA	NA	91,500 r/	612,000 r/
1999	NA	NA	118,000	558,000	21.2	NA	NA	77,700 r/	533,000 r/
2000	NA	NA	139,000	589,000	23.6	NA	NA	98,600	587,000
Copper: 9/									
1996	891,000	428,000	1,320,000	3,720,000	35.4	2,140,000	1,030,000	3,170,000	8,950,000
1997	967,000	498,000 r/	1,460,000	3,900,000 r/	37.5 r/	2,380,000 r/	1,170,000	3,450,000	9,210,000 r/
1998	956,000	466,000	1,420,000	3,980,000	35.7	1,660,000	808,000	2,470,000	6,900,000
1999	949,000 r/	381,000	1,330,000	4,080,000	32.7	1,590,000	637,000 r/	2,220,000 r/	6,820,000
2000	952,000	363,000	1,310,000	4,060,000	32.4	1,850,000	705,000	2,550,000	7,890,000
Iron and steel: 10/									
1996	NA	NA	71,000,000	121,000,000	59	NA	NA	9,270,000	15,800,000
1997	NA	NA	73,000,000	127,000,000	58	NA	NA	9,520,000	16,500,000
1998	NA	NA	73,000,000	133,000,000	55	NA	NA	7,910,000	17,400,000
1999	NA	NA	71,000,000	130,000,000	55 r/	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
Lead: 11/									
1996	37,500	1,020,000	1,050,000	1,660,000	63.7	40,400	1,090,000	1,140,000	1,790,000
1997	54,000	1,030,000	1,090,000	1,660,000	65.4	55,400	1,060,000	1,120,000	1,700,000
1998	45,800	1,050,000	1,100,000	1,740,000	63.1	45,700	1,050,000	1,100,000	1,740,000
1999	42,700	1,050,000	1,090,000	1,790,000	60.9	41,200	1,010,000	1,050,000	1,730,000
2000	35,400	1,080,000	1,120,000	1,790,000	62.6	34,000	1,040,000	1,080,000	1,720,000
Magnesium: 12/									
1996	41,100	30,100	71,200	205,000	35	170,000	125,000	295,000	850,000
1997	47,000	30,500	77,600	233,000	33	172,000	112,000	284,000	851,000
1998	45,200	31,800	77,100	226,000	34	158,000	111,000	284,000	788,000
1999	52,000 r/	34,200 r/	86,100 r/	231,000 r/	37 r/	178,000 r/	117,000 r/	294,000 r/	789,000 r/
2000	52,200	30,100	82,300	209,000	39	158,000	90,800	248,000	630,000
Nickel: 13/									
1996	NA	NA	59,300	206,000	28.8	NA	NA	445,000	1,540,000
1997	NA	NA	68,400	222,000	30.8	NA	NA	474,000	1,540,000
1998	NA	NA	63,100	212,000	29.7	NA	NA	292,000	983,000
1999	NA	NA	71,000	211,000	33.6	NA	NA	427,000	1,270,000
2000	NA	NA	84,000	231,000	36.4	NA	NA	725,000	1,990,000
Tin: 14/									
1996	3,930	7,710	11,600	37,400	31	35,600	69,900	106,000	339,000
1997	4,540	7,830	12,400	48,600	25	38,200	65,600	104,000	409,000
1998 15/	8,470	7,790	16,300	54,600	30	69,600	64,000	134,000	449,000
1999 15/	8,650	7,720 r/	16,400 r/	57,300 r/	29 r/	70,400 r/	62,800 r/	133,000 r/	466,000 r/
2000 15/	8,450	6,600	15,100	52,100	29	68,800	53,700	122,000	424,000
Titanium: 16/									
1996	NA	NA	26,300	W	48	NA	NA	50,700 e/	NA
1997	NA	NA	28,200	W	46	NA	NA	37,600 e/	NA
1998	NA	NA	28,600	W	50	NA	NA	22,100 e/	NA
1999	NA	NA	21,900	W	55	NA	NA	28,900 e/	NA
2000	NA	NA	18,500	W	50	NA	NA	38,200 e/	NA
Zinc: 17/									
1996	266,000	113,000	379,000	1,450,000	26.1	274,000	114,000	388,000	1,640,000
1997	286,000	89,700	376,000	1,490,000	25.2	376,000	118,000	495,000	1,960,000
1998	344,000	89,900	434,000	1,580,000	27.5	352,000	92,100	444,000	1,620,000
1999	321,000	78,100 r/	399,000 r/	1,610,000	24.8 r/	379,000 r/	92,200 r/	471,000 r/	1,900,000 r/
2000	369,000	66,900	436,000	1,610,000	27.1	454,000	85,600	540,000	2,060,000

See footnotes at end of table.

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

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. Home scrap 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 on a monetary value basis.
7/ Scrap quantity 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. Monetary value based on U.S. annual average composite price for No. 1 heavy melting steel calculated from prices published in American Metal Market.
11/ 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.
12/ Includes magnesium content of aluminum-base scrap. Monetary value based on the annual average Platt's Metals Week's U.S. spot Western price.
13/ Nickel statistics were derived from the following:

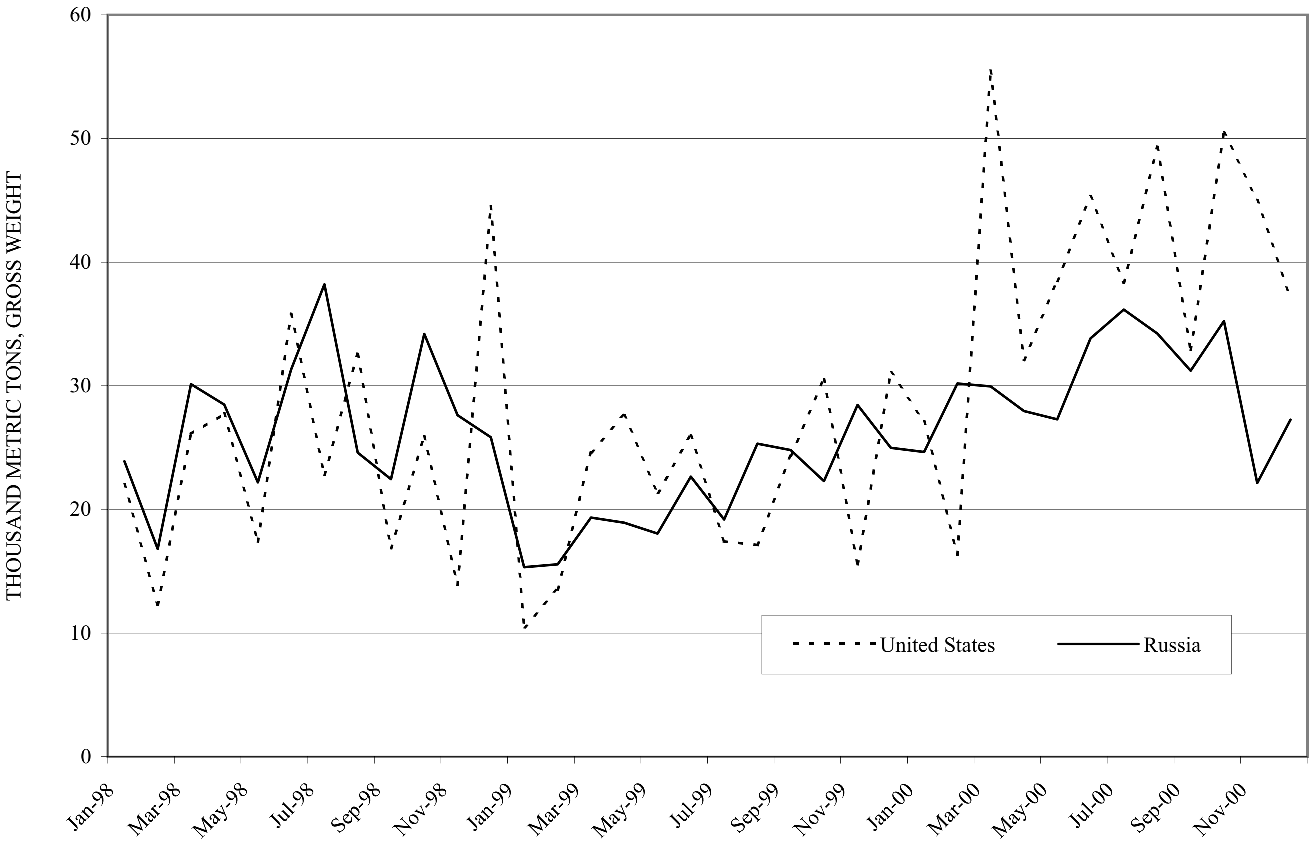
Canvass data
- Reported nickel content of products made from reclaimed stainless steel dust, spent nickel-cadmium batteries, plating solutions, etc.
- Estimated nickel content of reported net receipts of alloy and stainless steel scrap.
- Reported nickel content of recovered copper-base scrap.
- Reported 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.
14/ Monetary value based on Platt's Metals Week Composite price for tin.
15/ 1998 to 2000 new scrap data include data unavailable for 1996 and 1997.
16/ Percentage recycled based on titanium scrap consumed divided by primary sponge and scrap consumption.
17/ Monetary value based on annual average Platt's Metal Week metal price for North American special high-grade zinc.

FIGURE 1
EXPORTS OF STAINLESS STEEL SCRAP
RUSSIA AND UNITED STATES



Source: International Nickel Study Group. Russian export data as reported by importing countries.