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 the quantity of supply available for use at any point in time by developing economic processes for the recovery of primary metal (i.e., from the Earth) and secondary metal (i.e., from the use process stream). The reusable nature of metals contributes to the sustainability of their use.

Recycling, a significant factor in the supply of many of the metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of waste, and reduced emissions associated with energy savings. Table 1 shows salient U.S. apparent supply and recycling statistics for selected metals. Apparent metal supply of 149 million metric tons (Mt) was valued at $39.8 billion in 1999. By weight, iron and steel accounted for 87.6% of apparent supply. By value, aluminum accounted for 36.1% of apparent supply and iron and steel accounted for 30.8%. Recycling contributed 77.9 Mt of metal, valued at about $16.8 billion, or over one-half of metal apparent supply by weight.

The U.S. Geological Survey (USGS) collects, analyzes, and distributes information about more than 100 raw and/or processed minerals. Mineral commodity specialists assess collected data, and information is disseminated to government, industry, academia, and the general public through more than 100 commodity-series, periodical publications. This Mineral Industry Surveys Annual Review summarizes metal recycling. Separate annual reviews are published for each of the metals summarized in this report. Those separate 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 chapter. 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 (UBC's) are an example 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.

The Defense Reutilization and Marketing Services of the Defense Logistics Agency planned to move the receiving, handling, sorting, segregating, and processing of about 250,000 metric tons (t) of ferrous and nonferrous scrap from the agency to private contractors (Recycling Today, 1999).

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.

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 increased by 9% in 1999 compared with that of 1998. Of the 3.75 Mt of recovered metal, 59% came from new (manufacturing) scrap, and 41%, 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., 63.9 billion aluminum UBC's were recycled in the United States in 1999. The recycling rate was 62.5%, which was a slight decrease from the 62.8% recycling rate reported in 1998; the rate is based on the number of cans shipped during the year. This was the 11th consecutive year in which the aluminum can recycling rate was greater than 60%. According to the organizations' joint press release, aluminum

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beverage cans produced domestically in 1999 had an average 51.2% recycled content, the highest average recycled content percentage of all packaging materials (Aluminum Association Inc., 2000).

Purchase prices for aluminum scrap, as quoted by American Metal Market, followed the general trend of primary ingot prices and scrap prices, which closed the year at significantly higher levels than those at the beginning of the year, and averaged more than 10 cents per pound higher than those at yearend 1998. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 53.5 to 54.5 cents per pound; old sheet and cast aluminum, 48.5 to 49.5 cents per pound; and clean, dry aluminum turnings, 48.5 to 49.5 cents per pound.

Aluminum producers' buying price range for processed and delivered UBC's, as quoted by American Metal Market, also trended upward during the year. The price range began the year at 44 to 45 cents per pound and closed the year at 57 to 59 cents per pound. Resource Recycling published a monthly transaction price for aluminum UBC's in its Container Recycling Report. During the year, the monthly average increased significantly from 44.4 cents per pound in January to 59.6 cents per pound in December. Similar to the U.S. market price trend of primary aluminum ingot, however, the annual average price for 1999 of 50.6 cents per pound was only marginally higher than the 1998 annual average of 50.0 cents per pound.

The yearend indicator prices for selected secondary aluminum ingots, as published in American Metal Market, also increased significantly compared with those of 1998. The closing prices for 1999 were as follows: alloy 380 (1% zinc content), 78.34 cents per pound; alloy 360 (0.6% copper content), 81.78 cents per pound; alloy 413 (0.6% copper content), 81.48 cents per pound; and alloy 319, 81.06 cents per pound. Platt's Metals Week published an annual average U.S. price of 65.05 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 54.03 cents per pound.

Beryllium[3]

Beryllium is used in many applications where such properties as light weight and stiffness are important. In 1999, 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 1999, U.S. apparent consumption of beryllium totaled about 385 t. 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, 2000a; Petkof, 1985).

Cadmium[4]

The quantity of secondary or recycled cadmium is difficult to estimate for several reasons. In the recycling of baghouse dusts from lead and copper smelters, for example, the recovered cadmium subsequently enters primary cadmium production circuits at zinc refining operations and is included in the production statistics for primary cadmium metal. There are no firm figures on the amounts of cadmium recovered from 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 1999 world primary production.

Recycling of cadmium is a young and growing industry spurred by environmental concerns and regulatory moves to limit dissipation of cadmium into the ground from discarded cadmium products. Because about three-fourths of cadmium is used in nickel-cadmium (NiCd) batteries, and because batteries are easy to recycle, most of the secondary cadmium comes from spent NiCd batteries. 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 diecasting. 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 1999, the annual rate of secondary production in the United States amounted to about 500 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 (HTMR) process. Cadmium in smaller sealed batteries is recovered by burning off the castings and separators at a lower temperature than used in the HTMR process. The resulting 99.95% pure cadmium is

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shipped to battery manufacturers for reuse.

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 contain nickel (austenitic) and which do not (ferritic). Nickel content increases the price of the alloy and its resulting scrap.

Scrap is generated during the manufacturing process (new scrap) and as a result of recycling obsolete equipment (old scrap). Scrap from these sources is collected and sorted by grade (i.e., chemical composition) in scrap yards. Scrap brokers play a role in moving material from where it is recovered to where it is consumed. The steel industry consumes stainless steel scrap as a source of chromium and nickel units. 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 1999, scrap consumption reported by U.S. cobalt processors and consumers was 2,720 t of contained cobalt, a decrease of 12% from the 3,080 t consumed in 1998. U.S. imports of cobalt waste and scrap decreased by 54% to 391 t, gross weight, valued at $4.1 million. Seven countries supplied more than 90% of these materials—the United Kingdom, 40%; Germany, 16%; Japan, 10%; Canada and France, 9% each; and Belgium and the Netherlands, 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 (2000, p. 16), estimated world production of secondary refined copper declined for the second consecutive year, falling to 1.88 Mt in 1999, down from 2.07 Mt in 1998, and accounted for only about 13% of total world production of refined copper. According to data compiled by the World Bureau of Metal Statistics (2000, p. 42), an additional 3.22 Mt of copper was recovered from the direct remelting of copper scrap, a decline of almost 100,000 t from that of 1998. Secondary refined production in the United States continued its downward trend, declining by more than 100,000 t, 30%, in 1999. Conversely, copper recovered in alloys and chemicals, direct melt scrap, continued an upward trend, rising by about 30,000 t, 3%. Copper scrap prices generally followed the trend in refined copper prices, which declined during the first quarter from the already low prices at yearend 1998 before beginning a steady recovery. Though the monthly average producer price rose to 85 cents per pound in December, the annual average price of refined copper, 76 cents per pound, was at its lowest level since 1986. The low prices squeezed processing margins and the discount to refined copper narrowed for all scrap types. The discount to the producer price for refined copper for No. 1 and No. 2 scrap fell to 4.1 cents and 15.4 cents per pound, respectively, in March and averaged 5.0 cents per pound and 18.4 cents per pound, respectively, for the year.

While global trade in copper scrap declined in 1999, U.S. exports of copper scrap of 314,000 t (estimated copper content of 250,000 t) were essentially unchanged. The United States regained its position as the largest international source for copper scrap, having relinquished that distinction during 1998 to Russia, whose exports fell sharply in 1999 to about 200,000 t. Exports from Germany also declined sharply, falling by 55,000 t to 272,000 t (International Copper Study Group, 2000, p. 40-43). China was the largest recipient of scrap, accounting for about 45% of global scrap imports. It was also the largest recipient of U.S. scrap, accounting for 27% of scrap exports. U.S. imports of copper scrap declined by 56,000 t to 211, 000 t. Canada and Mexico were the leading sources for U.S. imports of copper and copper alloy scrap and accounted for 73% of imports in 1999.

During 1999, two secondary smelters and four fire refineries processed scrap to recover unalloyed copper products in the United States. One electrolytic refinery was a dedicated facility associated with a secondary smelter and mostly processed anode derived from scrap; several refineries, principally associated with primary smelters, processed some secondary anode. One fire refinery in Missouri, Warrenton Refinery, closed during the year and a second had very limited production. Coinciding with industry reports of tight supplies and low margins for high-grade scrap, on March 19, Philip Services Corp. closed its 32,000-ton-per-year (t/yr) Warrenton

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Refinery and placed it on the market (Platt's Metals Week, 1999). While no secondary facility closed during the year, closures that occurred in 1998 led to reduced production in 1999. 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 17%; brass mills, 62%; brass and bronze ingot makers, 10%; and miscellaneous manufacturers (including aluminum and steel alloy producers), foundries, and chemical plants, 11%. Alloyed copper products accounted for about 80% of the total copper recovered from scrap.

In 1999, copper recovered from all refined or remelted scrap (about 30% from old scrap and 70% from new scrap) composed 33% of the total U.S. copper supply and had an equivalent refined value of $2.3 billion. As a result of a drop in copper prices and a decline in old scrap consumption, the equivalent refined value of copper recovered from scrap fell by about 10% in 1999, and was down by 35% from the 1997 production value of $3.5 billion. Copper recovered from old scrap declined by about 18% to 380,000 t, the lowest value since 1975, and copper recoverable from purchased new scrap, 956,000 t, was essentially unchanged from that of 1998. Almost 90% of the copper recovered from new scrap in 1999 was consumed at brass mills.

High copper prices generally encourage collection of old scrap and also encourage consumption by increasing processing margins at secondary smelters, refiners, and direct remelters of scrap. Copper recovery from old scrap, and total old scrap generation (old scrap recycled plus estimated net exports of scrap) reached an all-time peak in 1980, a period of high copper prices. Conversely, low prices discourage the recovery of old scrap, and old scrap recovery fell following the 1982 recession. Despite record-high copper prices in 1995, total old scrap generation, assuming all trade in scrap to be old scrap, has never regained its 1989 postrecession peak of about 770,000 t, averaging only 600,000 t/yr during the period from 1995 to 1998. In 1999, old scrap generation fell to about 520,000 t owing to the impact of sustained low copper prices and reduced domestic processing capacity. Net imports of scrap in 1999 contained an estimated 140,000 t of copper and were essentially unchanged from those of 1998.

In addition to the immediate impact of low copper prices, the secondary copper smelting/refining industry, the largest consumer of old scrap, has been increasingly affected by environmental legislation, which increased operating and capital costs. The industry has also been affected by competition from foreign consumers of scrap, which raised copper scrap buying prices relative to refined prices and effectively reduced processing margins. In 1985, eight secondary copper smelters were operating in the United States. With the shutdown of a small secondary smelter in California, followed by the closure of Amax Copper Inc.'s large secondary smelter in Carteret, NJ, the attrition of domestic secondary smelting capacity has been steady. By yearend 1998, only two secondary smelters remained open. In early 1999, Southwire Company, a major producer of copper and aluminum wire, placed its secondary copper smelter and associated electrolytic refinery in Carollton, GA, on the market as part of a restructuring plan aimed at lowering costs. In April 2000, having been unsuccessful in finding a buyer, Southwire announced its intent to close the facilities beginning in May. Southwire cited economic reasons for the closure, chief among them being the cost of environmental compliance in the Atlanta metro area (Southwire Company, 2000).

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 as much as 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

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parallel the price fluctuations of 99.99%-pure gallium metal. Also, prices are dependent on the type of scrap and its gallium content. 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, which consists of gold-containing products that have been recycled after use, generally contributes from 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 possession 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 this "home 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 also 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).

Refiners throughout the world recover gold from scrap. In the United States, about two-thirds of the scrap comes from manufacturing operations, and the remainder comes from old scrap in the form of such items as discarded jewelry and dental materials, 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, 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, 2000, p. 8).

Domestic consumption of new and old scrap was 73,000 and 100,500 kg, respectively. These data were collected in 1999 by the USGS and include 30,500 kg of imported scrap. In 1999, U.S. exports of gold scrap decreased for the third consecutive year, after 5 straight years of increase, and imports increased to their highest level since 1989. As it has been for many years, the United States was a net exporter of gold scrap in 1999.

According to USGS's statistical survey data, prices for gold waste and scrap imported and exported in 1999 averaged $96 and $235 per troy ounce, respectively; at the same time, the average price for gold was $280 per ounce (Platt's Metals Week, 2000, p. 10).

Indium[10]

Domestic recovery of secondary indium remained low for the third year since the unusually high level of 1996, when high prices temporarily encouraged the recycling of more old scrap. In 1999, as is typical in the United States, most of the secondary indium was recovered from new scrap. The actual quantity of secondary indium produced 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. In 1999, Japanese imports of indium totaled 91 t and ingot production of primary indium was 20 t, while the recycling of scrap provided about 55 t (Roskill's Letter from Japan, 2000).

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

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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 July 17, 2000, at URL http://www.recycle-steel.org/ fact/main.html).

The vast quantity of ferrous scrap available for recycling comprises home, prompt, and obsolete scrap. Prompt industrial scrap is generated from manufacturing plants that make steel products. Its chemical and physical characteristics are known, and it is usually transported quickly back to steel plants for remelting to avoid storage space and inventory control costs. Home or mill scrap is generated within the steel mill during production of iron and steel. Trimmings of mill products and defective products are collected and quickly recycled back into the steel furnace because their chemical compositions are known. The availability of home scrap has been declining as new and more efficient methods of casting have been adopted by the industry. Obsolete, old, or postconsumer scrap is also available for recycling. The largest source is junked automobiles, followed by demolished steel structures, 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 June 9, 1999, at URL http://www.recycle-steel.org/cars/autorec.html). Of the ferrous metal used to make a typical 1999 U.S. family vehicle, 44% was recycled metal. About 16,000 car dismantlers and 3,000 scrap processors produced about 12.9 Mt of iron and steel scrap from 13.5 million automobiles for recycling in 1999. This amount is about one-fourth of the ferrous scrap consumed by makers of pig iron and raw steel in the United States and enough steel to produce nearly 13 million new cars. (James Woods, Steel Recycling Institute, written commun.). Appliances, steel cans, construction steel, and other iron and steel products are also recycled.

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 EAF's and cupola furnaces. In 1999, BOF's were used to produce 54% of total steel in the United States while using only 20% of total scrap consumed (American Iron and Steel Institute, 1999, p. 74). During the same period, EAF's produced 46% of total steel while using 68% 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 enough energy 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 91% for automobiles, 95% for construction structural beams and plates, 77% for appliances, 58% for steel cans, and 64% overall (Steel Recycling Institute, A few facts about steel—North America's #1 recycled material, fact sheet, accessed July 17, 2000, at URL http://www.recycle-steel.org/fact/main.html).

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 developing steelmaking countries. The United States was no longer the leading exporting country of iron and steel scrap in 1998, as reported by the International Iron and Steel Institute (1999, p. 222). Germany took the lead, followed by Russia, the United States, Japan, France, Ukraine, the United Kingdom, and Canada. The four most significant importing nations were, in decreasing order of importance, Turkey, Spain, the Republic of Korea, and Germany (International Iron and Steel Institute, 1999, p. 224).

The U.S. trade surplus for all classes of ferrous scrap was 1.9 Mt in 1999 (U.S. Census Bureau, unpub. data, 1999). Total U.S. exports of carbon steel and cast-iron scrap went to 56 countries and totaled 4.7 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 31 countries and consisted of 260,000 t. The largest tonnages went to the Republic of Korea, Taiwan, Canada, and Spain. U.S. exports of alloy steel scrap (excluding stainless steel) were shipped to 45 countries and consisted of 559,000 t. The largest tonnages went to Canada and Mexico.

Lead[12]

About 76% of the 1.45 Mt of refined lead produced in the United States in 1999 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

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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 7% of the recycled lead was recovered from other lead-base sources including solder, cable covering, building construction materials, and drosses and residues (new scrap) from primary smelter-refinery operations.

Recycled lead currently is produced domestically by 20 companies operating 28 lead recovery plants. Of the 1.09 Mt of lead recycled in 1999, about 98% was produced by 8 companies operating 16 secondary smelter-refineries in Alabama, California, Florida, Georgia, 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 1999.

During the period 1995 through 1999, the United States exported an average of about 99,000 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 smelter's 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 1999, the supply of spent (scrap) lead-acid batteries for secondary smelters increased slightly compared with the tight supply that existed throughout most of 1998. The failure rate of automotive batteries remained fairly level, as the lack of any sustained temperature extremes continued in the more heavily populated regions of the United States for the fourth consecutive year. Secondary smelters were able to maintain production levels equivalent to that of the previous year. Stocks of refined secondary lead increased by 2% at yearend as battery manufacturers maintained a moderate supply of finished batteries. At yearend, the market price for whole scrap batteries averaged about 4 cents per pound, translating to a lead price of 8 cents per pound, assuming that lead accounted for about 50% of battery weight.

In March 1999, Metalico Inc., Cranford, NJ, purchased Gulf Coast Recycling Inc.'s secondary lead smelter in Tampa, FL. The smelter was reported to have a production capacity of about 64 t of lead per day (Ryan's Notes, 1999b, p. 3). Metalico also owns a secondary smelter in College Grove, TN, that the company acquired from General Smelting and Refining Inc. in December 1997.

Negotiations were terminated in July 1999 between Quexco, the Texas-based holding company (whose assets include RSR Corp., Dallas, TX, a secondary lead producer) and GNB Technologies Inc., Atlanta, GA, a secondary lead and lead-acid battery producer, ending Quexco's 18-month effort to purchase GNB's lead operations. According to a Quexco spokesperson, the company was unable to reach agreement with GNB's Australian-based parent company, Pacific Dunlop Ltd., regarding certain contractual terms (Metal Bulletin, 1999b, p. 11).

At the end of October, GNB Technologies Inc. closed its secondary lead smelter in Columbus, GA, for an indefinite period. The new facility had been in operation for about 4 years, but failed to reach its full production capacity of about 82,000 t/yr. According to a GNB official, the low price of lead and the cost of producing recycled lead at the Columbus plant prevented the plant from being competitive. Reopening of the facility remained a possibility, however, should there be a sufficient rise in lead prices. The company also noted that there were no existing plans to sell the smelter (Metal Bulletin, 1999a, p. 10).

Sanders Lead Co. Inc., Troy, AL, a major producer of secondary lead, announced late in the year that the company was in the process of obtaining the required permits to add two smelting furnaces to its existing four-furnace facility. The additional furnaces would increase plant production capacity to about 145,000 t/yr from the current 110,000 t/yr (Ryan's Notes, 1999a, p. 4).

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, such as flashings, 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 processed at the diecasting facility or sold to a scrap processor. The other types of scrap are either sold to a scrap processor or are directly used in steel desulfurization, a dissipative application.

Old magnesium-base scrap, or postconsumer scrap, consists of material such as lawnmower decks, used tools, automotive parts, helicopter parts, 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, some of the magnesium is recycled with the aluminum alloy. 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.

Old aluminum-base scrap consists of a variety of materials, but the most important magnesium-containing component is UBC's. Because of the high recycling rate (about 63% in 1999), UBC's represent about three-quarters of the magnesium-containing old aluminum-base scrap that is processed. UBC scrap is recycled exclusively into aluminum cans, so the magnesium recovered from this product can be recycled as many times as the aluminum cans are recycled.

Magnesium scrap arrives at the recycler either loose on a

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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 aluminum, because of its softness, 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 and 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 either 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.

Trade in magnesium scrap represents a small portion of the overall U.S. supply of magnesium-base scrap. In recent years, exports have been two to three times higher than the level of imports, with Canada as the leading destination for these exports. Much of this scrap is processed by primary producers in Canada and returned to the United States as diecasting alloys.

As more magnesium is used in diecastings for automotive applications, North American firms plan to construct new magnesium recycling plants. These plants primarily are expected to process new scrap resulting from automotive component diecasting operations, although many of them also will be able to process less pure grades of scrap. Many diecasters are beginning to recycle magnesium alloy scrap in their own operations.

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, contain 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, and 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's 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 (Watson, Andersen, and Holt, 1998).

Mercury[15]

Secondary mercury is recovered from a variety of source materials in response to 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]

Molybdenum containing spent catalysts were recycled into new catalysts and into superalloys. The U.S. superalloys industry consumed about 460 t of 99.9% pure molybdenum from spent catalysts. Molybdenum contained in alloy steels and iron was also recycled into new products when alloy steel and iron alloys were recycled. The use of such scrap was for other alloying components. While the molybdenum values were counted, they were not reported.

Nickel[17]

For the stainless steel scrap industry worldwide, 1999 and 1998 were difficult years financially (Gardner, 1999). Profit margins for scrap suppliers were especially thin in the first half of 1999 because of depressed nickel prices. The monthly LME cash price for 99.8% pure nickel gradually improved during 1999, recovering from a near-record low of $3,878 per metric ton in December 1998 to $8,083 per metric ton in December. Russia and the United States were the largest exporters of stainless steel scrap in both years.

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Russian stainless steel scrap and nickel alloy scrap exports to Western Europe increased significantly between 1995 and 1997. Declining prices resulted in a slackening of exports in the second half of 1998. Early in 1999, the Russian Government imposed tariffs on scrap metal exports in an attempt to eradicate illegal exports of stolen metals. Theft has been a serious problem for the restructured Russian economy. Nickel and six other scrap metals were subject to the new 20% export tariff (Reuters Limited, 2000a, b). Largely because of the tariff, Russian exports of stainless steel scrap fell almost 22% between 1998 and 1999, dropping from 326,000 t gross weight to 255,000 t (International Nickel Study Group, 2000, p. 72-73). Part of the drop in stainless steel scrap exports during the first half of 1999 may also have been due to extremely low prices, encouraging dealers to stockpile material in anticipation of better times. Russian scrap exports recovered in the second half of 1999 when nickel prices strengthened enough to offset the tariff. In November 1999, the tariff was raised to 30% (Interfax International Ltd., 2000). As a result of the increased scrap exports to Western Europe in the second half of 1999, the price of nickel in scrap decreased to 88% to 90% of the LME cash price at yearend 1999 (Reuters Limited, 2000b). Discounts in the United States were smaller than those in Europe, with U.S. scrap prices equivalent to about 95% of LME nickel values. Scrap exports continued to rise during the first half of 2000 and returned to 1997 levels. (See figure 1.)

In February 1999, the Russian Government imposed a 5% export tariff on refined nickel in response to demands from the International Monetary Fund that federal budget revenues be bolstered before fresh lending could resume (Bhar, 1999). The Russian tariff was to last for only 6 months, but was extended into 2000 and raised to 10%. The new tariffs and regulations left nonferrous scrap brokers in a more precarious position than the primary producers.

Stainless steel scrap is the largest source of secondary nickel for the United States, accounting for about 80% of the 71,000 t of nickel reclaimed in 1999. The 80% 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). An additional 2% came from the recycling of alloy steel scrap. The five leading producers of austenitic (nickel containing) stainless steel in the United States all have their principal meltshops in Pennsylvania. An additional eight companies have medium to small meltshops scattered throughout the eastern United States that make austenitic stainless products largely for niche markets.

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 21 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.

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 1999. Scrap in this category comes from a myriad of sources and includes cupronickel (a series of copper 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 wrought aluminum alloys containing 0.2% to 2.3% nickel, such as those designated 2218, 2618, 4032, 8280.

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. Discarded engine parts are deliberately nicked with a saw to prevent them from illegally entering the replacement parts market.

The U.S. collection and recycling program for nickel-cadmium and nickel-metal hydride batteries is in a period of rapid expansion. Federal legislation, especially that 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. The RBRC pays shipping costs from the collection site to Inmetco plus all reclamation charges. Brazil, Japan, and 10 European countries have similar programs. More than 4,500 t (gross weight) of NiCd batteries were collected worldwide in 1998 (England, 1999).

The North American scrap metal processing industry has undergone massive restructuring since 1996. Many of the smaller, family-owned scrap processing companies have been taken over by one of five rapidly growing conglomerates. Several of the acquisitions occurred in the Pittsburgh area and were designed to provide synergies for cost reduction. Significant consolidations of metal recycling companies also took place in Chicago, Hartford, Houston, and Los Angeles. The closure of smaller processing yards, the sharing of sales expertise, the integration of computer databases, reduced management overhead, and one-stop shopping for scrap consumers should make U.S. scrap metals operations more competitive and efficient, so that the industry will be better able to weather large fluctuations in commodity prices.

For example in 1996, Metal Management Inc. moved to acquire several established scrap processors despite weakening metal prices and other near-term market problems (Marley, 1998). Among the acquisitions were Aerospace Metals Inc. of Hartford, CT; Hou-Tex Metals Co. Inc. of Houston, TX; Michael Schiavone & Sons Inc. of North Haven, CT; and Reserve Iron & Metal LP of Cleveland, OH. The last of the acquisitions came at time when scrap prices began to sharply decline, creating financial problems for the company. Metal Management was working with lenders to avoid bankruptcy. As part of a cost-savings move, the company merged two of its largest subsidiaries—the Issac Group and Reserve Iron—forming the Issac Reserve Group. The merger was expected to save Metal Management more than $1.5 million per year (Marley, 1999).

Keywell LLC was in the process of setting up three new facilities for processing nickel-bearing scrap. The facilities are in Fairless Hills, PA; Antwerp, Belgium; and Los Angeles, CA (Newman, 2000). The Fairless Hills facility, in the USX Industrial Park northeast of Philadelphia, became operational in March 2000. The Fairless Hills operation will process stainless steel scrap in bulk, while the Antwerp and Los Angeles facilities will focus on preparing superalloy and titanium scrap for sale to high-temperature alloy producers. A large part of the Antwerp output is expected to be exported to the United States. The Los Angeles facility was scheduled to open in the second half of 2000 and will consolidate shipments for forwarding to Keywell's Vac Air Alloys Division at Frewsburg, NY. The Frewsburg facility was acquired by Keywell in 1987 and reportedly is the largest processor of vacuum-grade superalloy and titanium scrap in the world.

World melting capacity for superalloys has increased significantly in recent years, with companies adding a variety of vacuum-induction melting furnaces, vacuum arc remelt furnaces, and electroslag remelting furnaces. Melters are increasing capacity to meet growing demand for superalloys in the aerospace, power generation, and petrochemical industries.

Superalloy scrap must be properly segregated, analyzed, and cleaned. Key alloys include: INCONEL 718 for aerospace, INCONEL 706 for land-based turbines, and INCONEL 625 and HASTELLOY C for scrubber units and pollution control equipment. Superalloy scrap processors now have to actively compete with stainless steel blenders and nickel-cobalt refineries for the scrap. Because of improvements in casting and machining technology, less superalloy scrap is being generated per pound melted than was the case 10 years ago. The recent downturn in the aerospace cycle has reduced demand for jet engine castings, products that contain 25% to 100% nickel. This decrease in demand, though, has been offset by growing sales of land-based turbines.

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.

A significant part of the ferrous metals industry is now using the World Wide Web to trade quotes on stainless steel and alloy steel scrap. BuyStainlessOnline Inc. of Bensalem, PA, launched one of the first web sites of this type in late 1999. The web site URL is http://www.buystainlessonline.com.

A large segment of the metals industry opposed a U.S. Department of Energy (DOE) proposal to decontaminate 6,000 t of radioactively contaminated nickel. The U.S. House Committee on Commerce also expressed its concerns to DOE. The U.S. Nuclear Regulatory Commission (NRC) has since held hearings on the matter. The Metals Industry Recycling Coalition has taken the position that no metal originating from 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, and the Nickel Development Institute (Kelly, 1999).

Platinum-Group Metals[18]

Despite their limited availability, platinum-group metals (PGM), and chemical compounds containing them, are extremely useful as catalysts in the chemical and petroleum industries, as conductors in the electric industry, in extrusion devices, in dental and medical prostheses, and in jewelry.

Moreover, since the beginning of the 1975 model year, new automobiles sold in the United States have been equipped with catalytic converters to chemically remove polluting substances from engine exhausts. The amount of PGM required in these devices is more than the total amount of all other U.S. uses of PGM combined.

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.

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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 a significant potential source of secondary palladium, platinum, and rhodium. In 1998, an estimated 10 t of platinum, 6 t of palladium, and 2 t of rhodium were available in the United States for recycling from autocatalysts.

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 accounted for 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, high processing costs have made it uneconomical to recover selenium from scrapped rectifiers.

In 1999, no secondary selenium was recovered in the United States. Wornout photoreceptor drums and scrap generated in the manufacture of new drums are exported for the recovery of the selenium content. An estimated 50 t of secondary selenium was imported; this was about 16% 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, has continued its decline owing to competition from other technologies, mainly organic photoreceptors. The shrinking market, together with low prices and surplus foreign secondary capacity, discourages the redevelopment of secondary capacity in the United States.

Silver[20]

About 1,800 t of silver, valued at $301 million, was recovered from scrap in 1999. Photographic scrap was estimated to have generated 1,300 t of silver, the largest part coming from spent fixer solutions, X-ray and graphic arts wastes, and a small quantity directly from color film negatives. The remainder was recovered from jewelers’ sweepings, spent catalysts, electronic scrap, and other heterogeneous silver bearing materials. U.S. industrial demand for silver in 1999 was about 7,000 t; mine production was 1,951 t.

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. 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 1999, U.S. apparent consumption of tantalum totaled about 555 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 (Cunningham, 1985, 2000b; Tantalum-Niobium International Study Center, 1996). In recent years, the recycling of tantalum in tantalum capacitors from carefully collected and sorted electronic components has acquired considerable significance. Tantalum recovery from tantalum capacitor scrap requires special techniques owing to the different types of capacitor scrap. Tantalum can be recovered from certain capacitor scrap by electrolysis and acid leaching.

Tin[22]

In 1999, 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, seven detinning plants, and most municipal collection-recycling centers. New tin scrap is generated mainly in the tin mills at six steel plants, scores of canmaking facilities, numerous brass and bronze plants, and many soldermaking plants. Most tin-scrap-processing facilities are close to the tin-using industries and to densely populated area, most of which are 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 old tinplate scrap in the form of used (postconsumer) tin cans. For most of this 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.

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The Steel Recycling Institute (SRI) continued to promote the recycling of used tin cans, which have 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 increased slightly in 1999 to 58%, up from 56% in 1998, and up substantially from 15% in 1988 (Steel Recycling Institute, 2000).

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

Titanium[23]

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

Most titanium scrap is recycled by titanium ingot producers. 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 Teledyne Inc., Howmet Corp., Lawrence Aviation Industries Inc., RMI Titanium Co., and Titanium Metals Corp. Numerous companies were involved in the generation, segregation, and processing of scrap for recycling.

In 1999, U.S. production of titanium ingot decreased by about 23% compared with that of 1998. Scrap supplied 55% of the titanium required for ingot production, a 10% increase compared with that of 1998. Although no data are available as to the percentage breakdown of sources of titanium scrap, it is estimated that less than 2% of titanium ingot production is derived from old scrap.

A continued decrease in the consumption of titanium metal by commercial aircraft producers significantly decreased demand for titanium metal. Subsequently, recycling of titanium scrap decreased by about 23% compared with that of 1998. Imports of titanium scrap decreased 29%, while exports increased 16% compared with those of 1998. The United States was a net exporter of titanium scrap in 1999, with exports exceeding imports by 2,860 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, and is led by, in descending capacity order, the United Kingdom, Russia, Japan, and the United States (Marx, 1995). In 1999, there were three known 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.

Lower production levels of titanium metal products have reduced the availability of scrap. If demand for titanium by the aerospace industry suddenly increases as it has in the past, a temporary shortage of titanium scrap is likely. Excess sponge capacity, however, would supplement demand for scrap. Recent increases in cold hearth melting capacity are expected to continue to increase scrap utilization over the long term.

Growth in the consumption of ultra low carbon steels for automotive applications and appliances is expected to increase demand for ferrotitanium. Given that the long-term growth trend for ferrotitanium imports has been about 19% per year, imports are expected to meet much of the future domestic demand for ferrotitanium.

Tungsten[24]

In 1999, 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 or used as a source of tungsten by another consuming industry or as a substitute for tungsten concentrate by tungsten processors (Smith, 1994, p. 4-14).

Cemented carbide scrap is recycled by several processes. Some of them 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

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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 1999, scrap consumption reported by U.S. tungsten processors and consumers was 5,250 t of contained tungsten, an increase of 57% from the 3,350 t consumed in 1998. The United States imported 1,440 t of tungsten contained in waste and scrap, valued at $8.3 million, which was approximately equal to the tungsten content of waste and scrap imports in 1998. Five countries supplied almost three-fourths of these imports—Russia, 24%; Japan, 22%; China, 12%; Germany, 11%; and the United Kingdom, 6%. U.S. exports of tungsten waste and scrap increased by 6% to an estimated 843 t of contained tungsten valued at $5.8 million. The leading destinations for these exports were Germany, 27%; the United Kingdom, 22%; Belgium and India, 9% each; and Taiwan, 7%.

Vanadium[25]

The principal use of vanadium is as an alloying element. Very small quantities of vanadium, often less than 1%, are alloyed with other metals to produce various ferrous and nonferrous alloys. Owing to the relatively small amount of vanadium involved, these alloys in general do not lend themselves to recycling for vanadium recovery. Vanadium is also used as a catalyst. It is estimated that catalyst consumption accounts 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 1999, about 30% of world's zinc production was produced from secondary materials—brass, diecasting 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 diecasting 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-sized (more than 1,000 t/yr) 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 pure zinc chemicals. IMCO Recycling Inc., Midwest Zinc Corp., and the Zinc Corporation of America are the largest users of secondary zinc.

Because of wide differences in the character and zinc content of scrap, the recycling processes of zinc-bearing scrap vary widely. The recycling of clean new scrap, mainly brass, rolled zinc clippings, and rejected diecastings, usually requires only remelting. In the case of mixed nonferrous shredded metal scrap, zinc is segregated 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 1999, trade in zinc scrap was small—about 2% of total domestic consumption. Nearly 92% of imported zinc scrap was supplied by Canada, and the major destination of U.S. exports was Taiwan (56%). 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 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, Oremet-Wah Chang, Albany, OR, and Western Zirconium Co., Ogden UT, using vacuum-arc-reduction melting practices.

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[28] Prior to January 1996, prepared by the U.S. Bureau of Mines.

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/									
1995	1,680,000	1,510,000	3,190,000	7,980,000	40	$3,190,000	$2,850,000	$6,040,000	$15,100,000
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	2,200,000	1,550,000	3,750,000	9,940,000	38	3,180,000	2,240,000	5,420,000	14,400,000
Chromium: 8/									
1995	NA	NA	112,000	565,000 r/	19.8	NA	NA	148,000 r/	687,000
1996	NA	NA	98,400	467,000 r/	21.1 r/	NA	NA	116,000 r/	456,000
1997	NA	NA	120,000	490,000 r/	24.5 r/	NA	NA	146,000 r/	499,000 r/
1998	NA	NA	104,000 r/	531,000 r/	19.5 r/	NA	NA	105,000 r/	469,000 r/
1999	NA	NA	118,000	558,000	21.2	NA	NA	85,500	367,000
Copper: 9/									
1995	874,000	442,000	1,320,000	3,410,000	38.6	2,670,000	1,350,000	4,020,000	10,400,000
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 r/	497,000 r/	1,460,000 r/	3,910,000 r/	37.2	2,350,000 r/	1,170,000	3,450,000 r/	9,230,000 r/
1998	956,000 r/	466,000	1,420,000 r/	3,980,000 r/	35.7 r/	1,660,000 r/	808,000	2,470,000 r/	6,900,000 r/
1999	950,000	381,000	1,330,000	4,080,000	32.7	1,590,000	638,000	2,230,000	6,820,000
Iron and steel: 10/									
1995	NA	NA	72,000,000	114,000,000	63	NA	NA	9,720,000	15,400,000
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 r/
1999	NA	NA	71,000,000	130,000,000	54	NA	NA	6,680,000	12,300,000
Lead: 11/									
1995	49,600	954,000	1,000,000	1,630,000	61.7	46,200	890,000	935,000	1,520,000
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
Magnesium: 12/									
1995	35,400	29,800	65,100	203,000 r/	32	150,000	126,000	276,000	857,000 r/
1996	41,100	30,100	71,200	205,000	35	170,000 r/	125,000	295,000 r/	850,000 r/
1997	47,000	30,500	77,600	233,000 r/	33 r/	172,000 r/	112,000 r/	284,000 r/	851,000 r/
1998	45,200 r/	31,800	77,100 r/	226,000 r/	34 r/	158,000 r/	111,000	284,000 r/	788,000 r/
1999	55,400	33,900	87,300	232,000	38	182,000	116,000	298,000	793,000
Nickel: 13/									
1995	NA	NA	64,500	216,000 r/	29.9 r/	NA	NA	531,000	1,770,000 r/
1996	NA	NA	59,300	206,000 r/	28.8 r/	NA	NA	445,000	1,540,000 r/
1997	NA	NA	68,400	222,000 r/	30.8 r/	NA	NA	474,000	1,540,000 r/
1998	NA	NA	63,100 r/	212,000 r/	29.7 r/	NA	NA	292,000 r/	983,000 r/
1999	NA	NA	71,000	211,000	33.6	NA	NA	427,000	1,270,000
Tin: 14/									
1995	3,880	7,720	11,600	43,300	27	35,800	70,800	107,000	397,000
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 r/	7,790 r/	16,300 r/	54,600	30	69,600 r/	64,000 r/	134,000 r/	449,000
1999 15/	8,650	7,700	16,300	57,200	28	69,800	62,100	132,000	462,000
Titanium: 16/									
1995	NA	NA	20,500	W	49	NA	NA	41,800 e/	NA
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
Zinc: 17/									
1995	242,000	111,000	353,000	1,460,000	24.2	298,000	137,000	435,000	1,800,000
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 r/	434,000 r/	1,580,000	27.5 r/	352,000	92,100 r/	444,000 r/	1,620,000
1999	321,000	85,100	406,000	1,610,000	25.2	345,000	91,600	437,000	1,730,000

See footnotes at end of table.

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

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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. Value calculated from quantity by using the average annual value of high-carbon ferrochromium, in dollars per metric ton of contained chromium as follows: 1996--976; 1997--1,020; 1998--882; 1999--658.

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 stocks changes for secondary producers. Monetary value of scrap and apparent supply estimated 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 scrap includes reported reclaimed nickel; estimated nickel content of reported alloy and stainless steel scrap receipts; reported nickel content of recovered copper-base scrap; reported nickel content of obsolete and prompt purchased nickel scrap (except stainless and alloy steel scrap); and estimated nickel content of various types of reported new and old aluminum scrap. Trade includes estimated nickel content of nickel cathode, pellets, briquettes, powder, flake, ferronickel, metallurgical-grade nickel oxide, a variety of nickel containing chemicals, nickel waste and scrap, and stainless steel scrap. Stocks include reported and estimated nickel content of scrap stocks (except copper); reported nickel content in stocks of nickel cathode, powder, oxide, and chemicals; reported nickel content in consumer stocks of various nickel content in consumer stocks of various nickel materials; and reported Government nickel stocks. Monetary value based on annual average London Metals Exchange cash price nickel cathode.

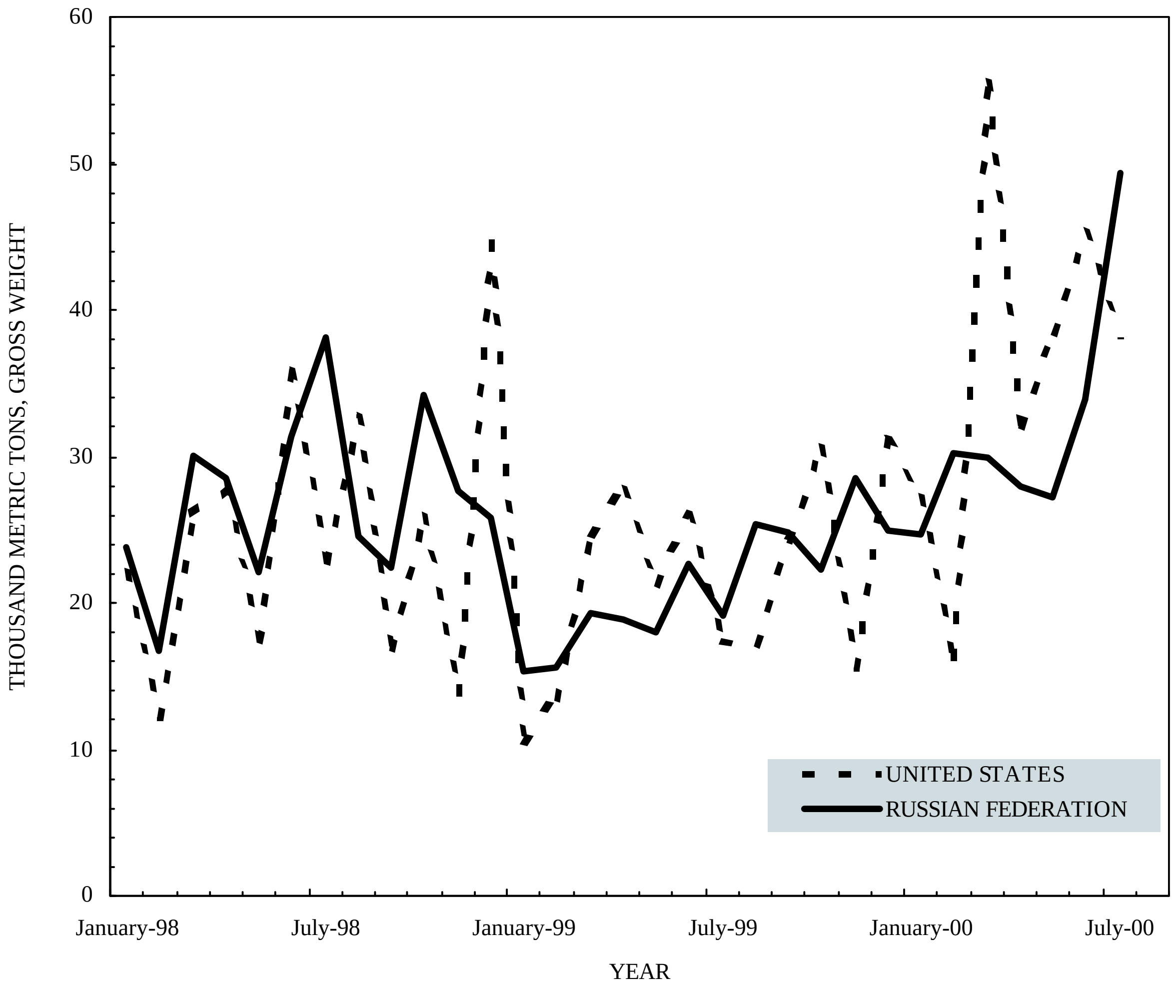
14/ Monetary value based on Platt's Metals Week Composite price for tin.

15/ 1998 and 1999 new scrap data includes data unavailable for 1995 to 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, RUSSIAN FEDERATION AND UNITED STATES



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