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Abstract: The metal forms of the metallic elements are almost the only mineral-derived materials that are recycled on a commercially and environmentally important scale. In 1990 secondary (recycled) metals produced in the United States were worth $37 billion, only $2 billion less than the value of primary (newly mined) metals. Twenty-two metals for which secondary recovery is important, in terms of quantity and/or value, are shown in the table below. Also included are the six platinum metals, represented as a group. In both quantity and value, iron, with its myriad steel alloys, is more important than all other metals combined. Five metals--iron, aluminum, copper, lead, and zinc--account for well over 99% of the quantity and just over 92% of the value of all secondary metal produced.

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BUREAU OF MINES

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RECYCLED METALS IN THE UNITED STATES

By Staff, Division of Mineral Commodities

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BUREAU OF MINES

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INTRODUCTION

Seventy-three of the 90 naturally occurring elements that are found in the earth's crust are metals or metalloids. The quantities of metals used annually in the United States range from about 100 million metric tons (steel) to a few kilograms (osmium). The recovery of metals from discarded products or industrial process wastes, especially those metals that are used in large quantity, are very expensive, or are unusually toxic, is important to the national economy and to the natural environment.

From its inception in 1910, the U.S. Bureau of Mines (USBM) has been the Government's prime source of information on metals recycling, as well as a major innovator in recycling technology. Statistical data on scrap generation and processing have been summarized annually for many years in the USBM's Minerals Yearbook. Most of the data for individual metals discussed in this report were extracted from that publication.

The discussion of recycling in this publication is focused on metals that are used to an important degree in metallic form. These are discussed individually. The discussion is further focused on recycling in the United States, although an attempt is made to put U.S. recycling into regional and world contexts. Metals that are used largely in mineral or compound form or in very small quantities are not discussed, nor are the nuclear fuel metals.

In several of the sections on individual metals, the quantities of secondary (recycled) metal are compared to total metal consumed as a means of illustrating the relative importance of recycling for each metal.

Definitions of the more important terms relevant to metals recycling are given in the Glossary, placed at the rear of the publication. For further information on recycling of metals, please contact:

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OVERVIEW OF METALS RECYCLING

The metal forms of the metallic elements are almost the only mineral-derived materials that are recycled on a commercially and environmentally important scale. In 1990 secondary (recycled) metals produced in the United States were worth $37 billion, only $2 billion less than the value of primary (newly mined) metals. By contrast, and with a few exceptions (common glass, asphalt paving, concrete), the compound forms of metallic elements (e.g. titanium dioxide, magnesium oxide, potash) and the bulk nonmetallic elements (e.g. sulfur, phosphorus, inert gases) are seldom recycled.

The form in which metals are recovered ranges widely. The precious metals, for example, usually are separated from other alloy metals and refined as individual metals; the ferroalloys, on the other hand, largely remain in steel as it is reprocessed. Metals are also recovered in compound form as oxides, chlorides, sulfates, etc.

Twenty-two metals for which secondary recovery is important, in terms of quantity and/or value, are shown in the table below. Also included are the six platinum metals, represented as a group. In both quantity and value, iron, with its myriad steel alloys, is more important than all other metals combined. Five metals--iron, aluminum, copper, lead, and zinc--account for well over 99% of the quantity and just over 92% of the value of all secondary metal produced.

The quantities of secondary metal shown in the table represent metal derived from both new and old scrap. The relative contribution of the two types of scrap ranges from nearly all new scrap (titanium) to nearly all old scrap (platinum group).

The contribution of secondary metal to total metal consumed ranges from greater than 70% (lead) down to about 5% (vanadium). Many factors determine the extent of secondary recovery of individual metals, including unit value, the size of the pool-in-use, the cost of collection and transport of scrap, the cost of metallurgical processing, the cost of disposal if the metal is not recycled, and the cost to the environment of nonrecovery. Without knowing the exact cost calculus, one may surmise that lead is the most intensively recycled metal because of some combination of large market, well organized collection of scrap from one dominant product (vehicle batteries) having a short and predictable life span, and great toxicity, which precludes disposal in landfills. The platinum metals, also, are intensively recycled, mainly because of their extremely high unit value, which insures that they are used in a relatively restricted set of industrial uses and carefully accounted for. Although secondary platinum and the other secondary precious metals taken together are quantitatively negligible, they account for 4% of the value of all secondary metals. Steel is intensively recycled because of the sheer size of the market, which makes possible a vast scrap collection and processing industry, and at the same time makes nonrecovery far too burdensome to the economy and the environment.

The 41 non-energy metals that are not represented in this publication encompass the 6 alkali metals, the 5 alkaline earths other than magnesium, 16 rare earths (scandium, yttrium, and 14 lanthanides), and 14 others. They have been omitted because the domestic use of each in metallic form is very small, and secondary recovery of them is usually negligible.

Recycling of Metals in the United States in 1990

Metal	Secondary (metal content, metric tons)	Percent of total secondary metal	Value of secondary metal (million dollars)	Percent of value of total secondary metal
Iron (incl. steel)	55,500,000	91	25,000	68
Aluminum	2,400,000	4	3,900	11
Copper	1,300,000	2	3,600	10
Lead	920,000	2	930	2
Zinc	340,000	1	560	2
Manganese	60,000	--	3	--
Magnesium	54,000	--	170	--
Nickel	25,000	--	220	--
Antimony	20,400	--	35	--
Titanium	15,000	--	140	--
Tin	7,800	--	65	--
Molybdenum	3,000	--	17	--
Tungsten	2,200	--	9	--
Silver	1,700	--	260	1
Cobalt	1,600	--	30	--
Cadmium	700	--	5	--
Selenium	100	--	1	--
Vanadium	100	--	2	--
Chromium	90	--	580	1
Mercury	90	--	<1	--
Platinum Group	71	--	660	2
Tantalum	50	--	18	--
Gold	49	--	600	2
Totals (rounded)	60,600,000	100	36,800	100

Al

ALUMINUM

by Patricia A. Plunkert

Salient Facts: Aluminum is the second most abundant metallic element in the Earth's crust after silicon, yet it is a comparatively new industrial metal that has been produced in commercial quantities for just over 100 years. It weighs about one-third as much as steel or copper; is malleable, ductile, and easily machined and cast; and has excellent corrosion resistance and durability. Measured in either quantity or value, aluminum's use exceeds that of any other metal except iron, and it is important in virtually all segments of the world economy. Aluminum is used in such products as beverage cans, foil wrap, automobiles, airplanes, trucks, windows, doors, aluminum siding, mobile homes, bridges, street signs, wiring, household appliances, outdoor furniture, and electronic devices to name just a few. It is difficult to find an aspect of human life that is not touched by some product that has an aluminum metal component. These end uses for aluminum metal are usually divided into seven major categories or industries: containers and packaging, transportation, building and construction, electrical, consumer durables, machinery and equipment, and other miscellaneous uses. In the United States, the container and packaging industry is the largest consumer of aluminum metal (about 35% of apparent consumption), followed by the transportation industry and the building and construction industry, both of which have about a 20% share of domestic aluminum consumption.

About 40% of the domestic supply of aluminum metal is metal recovered from both purchased new and old aluminum scrap. In 1991, 2.3 million metric tons (Mmt) of metal valued at an estimated $3.0 billion[1] was recovered from both new and old aluminum scrap. Aluminum scrap is traded on the world markets. In 1991, the United States imported just over 208,000 mt of aluminum scrap with a value of almost $220 million. Exports of scrap for the year totalled 461,000 mt and were valued at $542 million.

Aluminum scrap, in one form or the other, is recovered by almost every segment of the domestic aluminum industry. Integrated primary aluminum companies, independent secondary smelters, fabricators, foundries, and chemical producers can recover aluminum from scrap. Integrated primary aluminum companies and independent secondary smelters, however, are the major consumers of aluminum scrap.

The independent secondary aluminum smelter is the core of the commercial secondary aluminum industry. Unlike scrap dealers who buy and sell many different metals and die casters who cast other metals, the secondary aluminum smelter is totally dependent upon one metal — aluminum. The sole purpose of the secondary aluminum smelter is to transform aluminum scrap into a marketable product. Scrap is purchased by a smelter wherever it can be purchased economically. Purchasing habits can also depend on how badly a smelter needs scrap. During periods of excess scrap supply, smelters tend to be very selective in their scrap purchases. When the supply of aluminum scrap becomes short, however, they frequently buy scrap that they would not ordinarily process. Independent secondary aluminum smelters, by definition, consume scrap and produce alloys for the die casting industry. A cursory look at the distribution of these secondary aluminum smelters in the United States consequently reveals a heavy concentration of smelters in the automotive and appliance manufacturing areas of the country.

The other major consumer of aluminum scrap are the integrated primary aluminum companies. The types of scrap processed by these companies tend to be more segregated than those processed by the secondary smelters. 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 set up literally thousands of collection centers around the country for used aluminum beverage cans. The large scale aluminum beverage can reclamation programs of these aluminum producers have added substantially to the rate of aluminum recovery from old scrap.

Salient Aluminum Statistics, United States
(Thousand metric tons)

	1950	1960	1970	1980	1990
Apparent aluminum supply[1]	1,023	1,902	4,132	5,554	6,298
Secondary recovery[2]	221	397	907	1,577	2,393
Secondary recovery as percent of supply	22	21	22	28	38
U.S. scrap trade:					
Imports	62	5	33	54	214
Exports	1	72	52	403	537

[1] Primary metal production + metal recovered from purchased new and old scrap + imports - exports + adjustments for Government and industry stock changes.
[2] Metal recovered from purchased new and old scrap.

Sources of Secondary Aluminum and Industry Trends: Scrap is the unavoidable byproduct of fabricating operations or the product of obsolescence. Scrap resulting from semifabricating or fabricating operations is called new scrap while scrap resulting from obsolescence is called old scrap.

New scrap generated by the fabrication of aluminum products may be either home scrap (sometimes called runaround scrap) or prompt industrial scrap. Runaround or home scrap is new scrap that is recycled by the same company that generates it; such scrap never leaves the company generating it and, therefore, is never marketed as scrap; it is not included in the statistical data presented in this chapter. Prompt industrial scrap, however, is new scrap from a fabricator who does not choose to, or is not equipped to, recycle the scrap. This scrap then enters the secondary aluminum market as purchased new scrap.

New aluminum-base scrap, generated in the production of intermediate and end products of aluminum metal, may be pure (unalloyed), segregated (one alloy type) or mixed (two or more alloys). It includes solids, such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, and sweepings.

Old scrap, all of which is considered as purchased, becomes available to the secondary industry when consumer products (durable and nondurable) have reached the end of their economic life and have been discarded.

Old scrap includes such products as aluminum pistons or other aluminum engine or body parts from junked cars; used aluminum beverage cans and utensils; old wire and cable; discarded aluminum windows, doors, and siding; and used aluminum foil. Sweated pig is scrap that has been sweated or melted into a pig or ingot form for convenience and economy in shipping and storage. Obsolete scrap is new, unused, but technologically obsolete aluminum end products, outdated inventory materials, production overruns, and spare parts for machines and equipment no longer being used. In the United States, both sweated pig and obsolete scrap are considered old scrap.

The secondary aluminum industry was born shortly before World War I at a time when the United States had only one primary aluminum producer. There was little need for a secondary industry prior to that time since the supply of aluminum scrap was limited. Although the secondary industry did grow during and after World War I, that growth was modest until World War II. World War II created many changes in the aluminum industry. Primary aluminum production was no longer a monopoly, and the secondary industry had progressed from being a melter of scrap to a smelter technology. Secondary smelters emerged from the war years with the technology needed to process the huge quantities of aircraft scrap and other partially manufactured aluminum products. It was at this point in history that the secondary aluminum industry started its phenomenal growth.

Aluminum recovery from scrap has become an important component of the supply and demand relationship in the United States. Between 1950 and 1974, aluminum recovered from old scrap (post-consumer scrap) accounted for approximately 5% of the total domestic supply of aluminum. Increased energy costs and growing concerns over waste management have provided the impetus for increased recycling rates. In 1991, recovery from old scrap supplied about one-fourth of the total aluminum metal supply in the United States.

Aluminum recovered from scrap has shown a tenfold increase since 1950. The recovery of aluminum from old scrap has shown an even more rapid expansion over the same period of time. In addition to improvements in recycling technologies, some of the increase in aluminum scrap recovery can be attributed to a changing and growing end use consumption pattern. Aluminum products, developed for the construction, transportation, and electrical industries, tend to have a fairly long life cycle and are slow to enter the scrap supply stream. The emergence of the aluminum beverage can in the mid-1970's with a life cycle of less than 1 year added dramatically to the potential aluminum scrap supply. The used beverage can component of old scrap consumption has doubled since 1975.

Aluminum scrap is also traded in the international marketplace. Price and shipping costs are usually the determining factor in choosing whether to sell scrap in the domestic or international markets. U.S. trade in aluminum scrap has grown dramatically over the last 30 years. Most of the scrap shipped into the United States comes from Canada. Since the mid-1970's, the major recipient of U.S. scrap exports has been Japan.

The secondary aluminum industry has developed into a major market force in the domestic aluminum industry. The recycling of scrap provides a source of aluminum that not only helps the aluminum industry to maintain its growth but also helps to conserve energy and to slow the depletion of bauxite resources. In 1991, the U.S. Bureau of Mines (USBM) estimated that almost 2.3 Mmt of metal was recovered from purchased aluminum scrap. Of this total, just under 60% was recovered from old scrap.

Recovery Methods: In recycling, aluminum-base scrap is usually melted in gas- or oil-fired reverberatory furnaces of 30,000 to 100,000 pounds capacity. The furnaces have one or two charging wells separated from the main bath by a refractory wall that permits only molten metal into the main bath. The principal refining of aluminum-base scrap is the removal of magnesium by treating the molten metal with chlorine or with various fluxes such as aluminum chloride, aluminum fluoride, or mixtures of sodium and potassium chlorides and fluorides. To facilitate handling, a significant proportion of the old aluminum scrap, and in some cases new scrap, is simply melted to form sweated pig that must be treated further to produce specification-grade ingot.

Aluminum drosses containing about 30% metallics are usually crushed and screened to bring the metallic content up to about 60% to 70%. They are then melted in a reverberatory furnace, with the molten aluminum metal collecting on the bottom of the furnace. Salt slags containing less than 30% metallics may be leached with water to separate the metallics.

In addition to this classical dross-recycling process, a new dross treatment process using a water-cooled plasma gas arc heater (plasma torch) installed in a specially designed rotary furnace was patented recently. The new process eliminated the salt flux used in the conventional dross treatment process and reported recovery efficiencies of 85% to 95%.

Secondary Products: The major component of processed old scrap is used aluminum beverage can scrap. Aluminum industry officials have estimated that scrap recovery from can manufacturing and used aluminum beverage cans represents an average recycling content of 55% of can sheet being produced in the United States.

Most of the other types of old scrap are recovered in the form of alloys used by the diecasting industry; the bulk of these diecasts are used by the automotive industry. Some industry officials have estimated that of the aluminum used in cars today, 80% is aluminum recovered from scrap.

Metal Recovery from New and Old Scrap
(Thousand metric tons)

	1950	1960	1970	1980	1990
Metal recovered from new scrap	152	311	728	960	1,034
Metal recovered from old scrap	69	86	179	617	1,359
Total metal recovery	221	397	907	1,577	2,393

Scrap Prices and Price Sources: The pricing mechanism of the aluminum scrap industry is almost entirely dependent on the laws of supply and demand. The *American Metal Market (AMM)* publishes daily national average prices for a number of different types of aluminum scrap, among which are mixed low copper clips, old sheet and cast, turnings clean and dry, and used beverage can scrap. The *AMM* also publishes price quotations for various areas of the country.

In addition to scrap prices, the *AMM* also publishes daily price quotes for a number of secondary ingot alloys, for example, alloy 380 (3% zinc), alloy 380 (1% zinc), alloy 360 (0.6% copper), and alloy 319. In October 1992, the London Metal Exchange began 3-month trading on its new secondary aluminum alloy ingot contract. Cash trading began in January 1993.

Outlook: The driving forces behind the increasing use of resource recovery as an alternative to sanitary landfill are both economic and political. The increasing costs of suitable land for landfills, the stringent regulations on leachate control, and other costs are making resource recovery more attractive. Aluminum scrap has been the highest unit valued commodity recovered from municipal refuse. Estimates show that metals represent about 9% by weight of municipal solid waste (MSW), but only 3% of volume. While aluminum beverage cans make up less than 1% by weight of MSW, they frequently represent more that one-half of the revenue collected by municipal recycling programs. The public and industry have recognized the economic and ecological value of recycling aluminum cans. Because of aggressive promotion and expansion of collection methods, the volume of aluminum cans being recycled into the aluminum supply stream has increased dramatically year by year.

As the public and industry become more sensitive to the issue of waste management, the benefits of recycling will become more evident. The aluminum industry, with its long history of recycling experience and its vast network of collection centers, is well-positioned to take advantage of this increased interest. The domestic and world secondary aluminum industries should continue to expand. In the short term, the growing acceptance of the aluminum beverage cans (with their very short life cycle) in overseas markets could lead to a more rapid growth in the recovery of secondary aluminum in countries outside the United States. As the use of aluminum expands in other areas, such as the automotive industry, more scrap will eventually enter the market for recovery, and increase the secondary production levels in both the domestic and world markets of the future.

[1] Value based on average annual price of primary aluminum ingot.

Sb

ANTIMONY

by Daniel L. Edelstein

Antimony is a silvery-white, brittle metal having poor thermal and electrical conductivity. Because of its affinity for sulfur and metallic elements such as copper, lead, and silver, it is seldom found in nature as native metal. Antimony is produced from stibnite (antimony sulfide) ores and as a byproduct of base-metal smelting in about 25 countries. China is the world's largest mine producer of antimony, accounting for about 54% of estimated world production. Historically, domestic mines have supplied only a small fraction of the total U.S. supply of antimony; in 1991, primary antimony was recovered at one mine from a complex silver-copper-antimony sulfide and as a byproduct at one primary lead refinery. Most of the domestic supply of primary antimony was from imported concentrate, metal, and oxide. The principal use for primary antimony, accounting for 73% of primary reported demand in 1991, was the production of flame retardents used in plastics, textiles, rubber, etc.

In 1991, the 19,600 mt of antimony recovered from old scrap accounted for 47% of apparent domestic demand for antimony. New scrap, predominantly from lead and tin-base drosses and residues, amounted to only 1,300 mt. The recycling of spent lead-acid storage batteries (used in automotive and industrial applications) at secondary lead smelters was the dominant source of secondary antimony. At yearend 1991, 16 companies operated 23 battery breakers-smelters. A small quantity of secondary antimony is also recovered in babbitt, solder, and type metal. Secondary antimony is recovered as a lead alloy component and not as refined metal. Antimony is added to lead alloys used in the production of lead-acid storage batteries to improve the strength and castability of plate grids, straps, and terminals. Antimonial lead recovered at secondary lead smelters is recycled back to storage battery production. Thus, the end-use market for secondary antimony differs significantly from that of primary material. In 1991, 20,300 mt of secondary antimony were recovered in lead alloys. Because of the high recycle rate for lead-acid batteries and changes in battery technology in recent years that have reduced the per unit demand for antimony in this application, less than 10% of primary antimony is consumed in battery applications. Demand for low-maintenance or maintenance-free batteries which use very low antimony-lead or calcium-lead alloys has increased over the past 20 years. Antimony has the negative effect of causing hydrogen gasing at the plates which requires venting and results in evaporation of electrolyte. In the near term, recovery of antimony from secondary metals should remain at about current levels. It could decrease with time, however, as more calcium-lead batteries work their way through the recycle stream. In addition, with demand increasing for primary antimony, secondary antimony as a percent of apparent demand is expected to decline.

Salient Antimony Statistics, United States
(Metric tons, antimony content)

	1950	1960	1970	1980	1990
Apparent consumption	33,015	28,565	32,231	29,862	38,958
Recovered from old scrap:					
Tonnage	17,029	15,828	16,887	15,602	19,187
Percent of apparent consumption	52	55	52	52	49
Recovered from new scrap	2,804	2,410	2,548	2,445	1,164

Cd

CADMIUM

by Thomas O. Llewellyn

Salient Facts: Cadmium is mainly a byproduct of beneficiating and refining zinc metal from sulfide ore concentrates. It is also produced as a byproduct from processing lead ores and complex copper-zinc ores. About 55% of the total apparent cadmium consumption in 1992 was in nickel-cadmium batteries. The remaining 45% was distributed as follows: coating and plating, 14%; pigments, 16%; plastics and synthetic products, 10%; and alloys and other uses, 5%.

In the United States, a satisfactory collection and sorting infrastructure is not in place to generate an adequate supply of spent household nickel-cadmium batteries capable of sustaining commercial recycling operations.

Sources of Secondary Cadmium: Cadmium recycling has been practical only for nickel-cadmium batteries, some alloys, and dust generated during steelmaking in electric arc furnaces. The technology to economically recover refined cadmium from these dust sources has been developed but the amounts so far recovered are not known. Almost all the cadmium used in coating and plating, plastic stabilizers, and pigments occur at low concentrations and involve a large number of products that are difficult to identify. Collection and recycling of such products is almost impossible to achieve and most of this cadmium is dissipated into the environment or landfill.

Salient Cadmium Statistics, United States
(Metric tons)

	1950	1960	1970	1980	1990	1991	1992
Production	4,176	4,617	4,293	1,578	1,678	1,676	1,620
Estimated consumption	4,302	3,934	5,254	4,196	3,107	3,105	3,515
Exports	160	1,110	169	236	385	158	178
Imports	286	421	1,130	2,617	1,741	2,039	1,958

Recovery Methods: Cadmium from spent nickel-cadmium batteries and cadmium alloys can be recovered using pyrometallurgical or hydrometallurgical processes, although the former is generally used. Large cadmium batteries, normally heavier than 2 kilograms, are emptied of their electrolyte and dismantled mechanically; the separators are removed together with the plastic casings, and the cadmium is recovered by distillation from the plates. The plastic casings and separators of the small sealed batteries are burned off at a lower temperature prior to the higher temperature treatment required to volatilize and condense the cadmium.

A Pennsylvania company began commercial recovery of cadmium from stainless steel wastes in 1978 and since 1990, from industrial nickel-cadmium batteries. The recovered cadmium is then shipped elsewhere for further purification. In addition, a North Carolina company collects industrial nickel-cadmium batteries for recycling. The electrolyte in the batteries is emptied and purified for later use, while the dry batteries are packaged and shipped to the company's recycling plant in Sweden. There, the batteries are dismantled and the positive electrodes, composed of nickel, iron, and some graphite, are sold to the stainless steel manufacturing industry. The cadmium from the negative electrodes is recovered by distillation.

Cadmium is present as a trace element in many of the materials used to produce iron and steel. These materials include iron ore, coal, limestone, and scrap steel. A significant amount of the cadmium is associated with lead and zinc present in the scrap steel. Most of the cadmium in these materials is volatilized during the melting phase and subsequently collected as furnace dust. At current production levels, the electric arc furnace (EAF) dust being generated by the U.S. steel industry each year alone is estimated to contain 250 mt of cadmium. About 75% of this cadmium is recovered in crude form, some of which is processed further but most is believed to be stockpiled. This does not include dust from blast furnaces or basic oxygen furnaces.

The separation of cadmium in EAF dust is made by a two-stage-kiln volatilization process. In the first stage, certain metals including cadmium are volatilized to produce a crude but upgraded calcine. In the second stage, cadmium, chloride, fluoride, and lead are selectively volatilized to separate them from zinc oxide. The fume product, known as lead-cadmium concentrate, is further treated at a cadmium plant by acid leaching and electrowinning to produce cadmium metal. A lead-silver-rich residue product is sold to lead smelters.

Outlook: As a consequence of stricter environmental and health controls now in effect or under consideration, the recovery of cadmium from secondary resources, mainly batteries and steelmaking dust, is expected to increase significantly in the next decade.

Cr

CHROMIUM

by John F. Papp

Salient Facts: Chromite ore is the only primary source of chromium. The mineral chromite is used directly as a refractory material or is smelted or processed for use in the metallurgical and chemical industries. Based on the chromium contained in chromite ore and ferrochromium, the major chromium-containing commodities, about 70% of chromium is used domesticly by the metallurgical industry; 20% is used by the chemical industry; and 10% is used by the refractory industry. Of the chromium consumed by the metallurgical industry, 70% is used by the stainless steel industry. In 1991 a USBM survey of chromium ferroalloys and metal consumption indicated that about 80% of chromium was used in stainless and heat-resisting steel, 7% in alloy steel, 2% in superalloys, and 11% in other alloys.

U.S. apparent consumption of chromium is primary production (chromium contained in domestic mine production of chromite ore) plus secondary production (chromium contained in recycled scrap) plus net trade (imports minus exports) in chromium materials (including chromite ore, chromium ferroalloys and metal, and chromium chemicals) plus domestic consumer and producer stock changes of chromite ore and chromium ferroalloys and metal.

Chromium contained in stainless steel and other scrap is recycled. Both new and old scrap are collected by scrap processors and returned to stainless steel manufacturers. Secondary production is calculated as chromium contained in reported stainless steel scrap receipts. Apparent consumption of chromium and recycled fraction thereof are shown in figure 1. Figure 2 shows chromium recycled as a percent of chromium apparent consumption.

Sources of Secondary Chromium: Stainless steel and superalloy production scrap and products are the major source of chromium containing scrap. In 1992, reported stainless steel scrap receipts by stainless steel producers represented 100% of secondary production reported here.

Recovery Methods: Industry practice is to sort waste and scrap for recycling. Chromium-containing stainless steel is collected, processed, and returned to stainless steel manufactures for reuse. Processing may include changing the physical form of the scrap. Large pieces may be cut to smaller size, common sizes may be bundled for easier handling, and smaller sized pieces may be melted and cast into larger sizes. Some materials require cleaning or sorting before they can be recycled. Some processors melt and combine several alloys to produce master alloy castings that meet stainless steel or other alloy manufacturers' chemical requirements. Superalloy (nickel- and cobalt-base alloys used in the aerospace industry) recycling is carried out by certified recycling companies in cooperation with alloy producers and product manufactures. Small quantities of chromium metal waste and scrap are also traded.

Secondary Products: Chromium contained in recycled products is typically used in all the same products in which chromium from primary sources is used.

Scrap Prices and Markets: The price of chromium-containing stainless steel scrap is sensitive to the price and availability of its constituents from primary sources. Stainless steel is composed of two major categories: austenitic and ferritic stainless steel. Austenitic stainless steel requires nickel and chromium. Ferritic stainless steel requires only chromium. The price of austenitic stainless steel is driven mostly by the higher-valued nickel contained in the scrap.

Stainless steel scrap is an internationally traded material. The United States is a stainless steel scrap exporter. Stainless steel scrap trade has never been and is not now, considered as part of apparent consumption. As a result, it is also excluded from chromium trade salient statistics tables.

Stainless steel scrap prices vary by geographic location, but mostly, by type of scrap. Nickel containing stainless steel scrap is substantially more highly priced than nickel-free scrap. The consumer buying price of nickel-bearing stainless steel scrap, as reported in the March 4, 1993, *American Metal Market*, ranged from $525 per gross ton to $700 per gross ton; that of nonnickel grades ranged from $100 per gross ton to $170 per gross ton.

World Chromium Recycling: Stainless steel, superalloy, and chromium metal are produced primarily in Europe, Japan, and the United States. Stainless steel represents about 1% of steel production and is a specialized, small part of the steel market serving the need for durable, corrosion resistant steel. Yet stainless steel accounts for about 50% of chromium demand. Worldwide, stainless steel producers and manufacturers of stainless steel-containing products practice recycling for cost control and to promote competitiveness.

Outlook: Chromium recycling is expected to increase, driven by environmental regulations mainly in the industrial countries. Stainless steel use has been growing, so the availability of stainless steel obsolete scrap should continue to increase as well as the scrap generated as a result of processing that material.

Recycled chromium makes up about 20% of current apparent consumption. In 2000, secondary chromium is expected to rise to 25% of apparent consumption because of recycling growth and decline in nonrecycling uses.

Figure 1.
Annual chromium recycling
(Metric tons, chromium content)

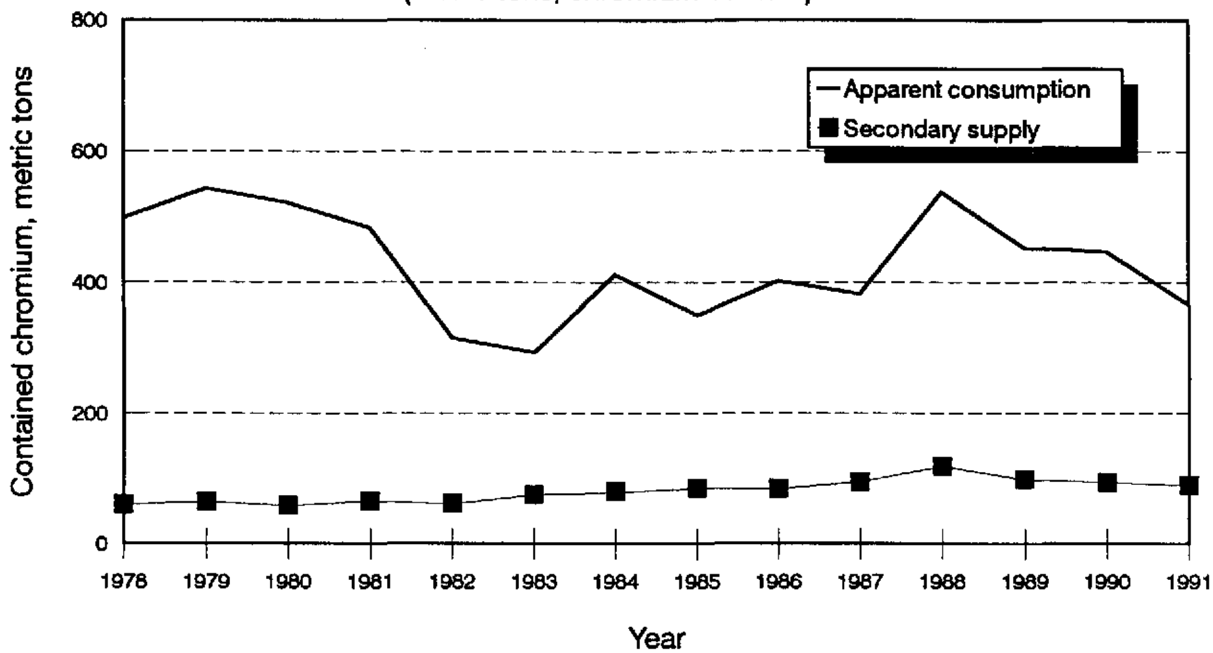
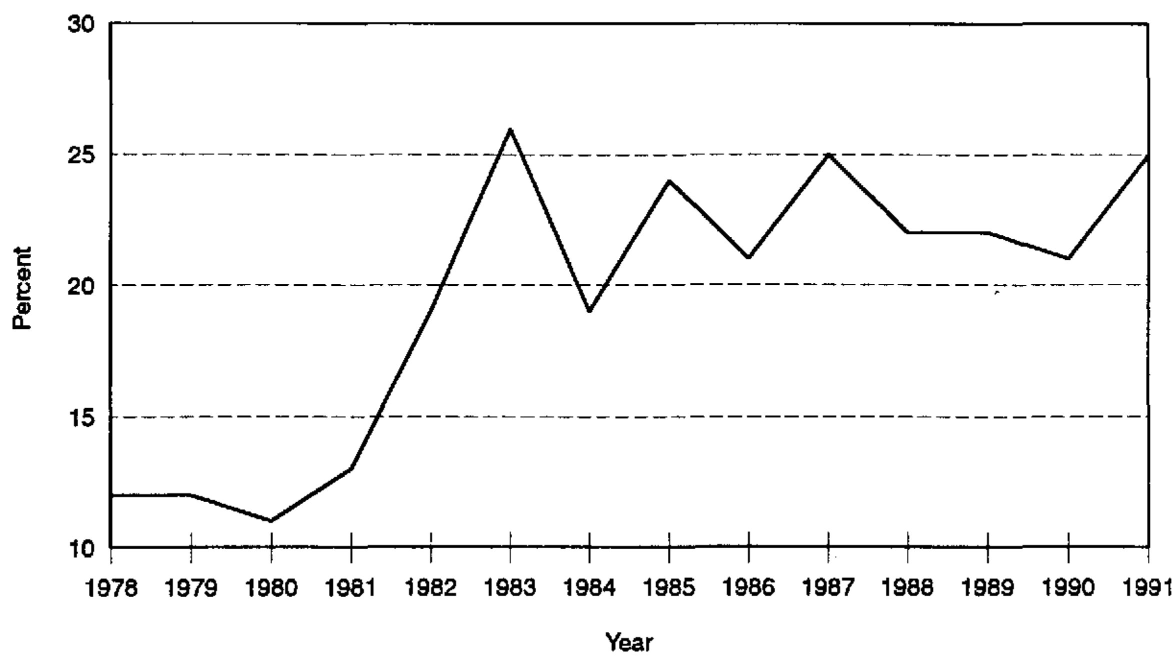


Figure 2.
Annual chromium recycling
(Secondary supply as a percent of apparent consumption)



Co

COBALT

by Kim B. Shedd

Salient Facts: Cobalt is a silvery-gray metal with many diverse uses. Eighty percent of U.S. cobalt consumption is in five major applications. Superalloys, used mainly in aircraft jet engines, account for 40% of U.S. consumption. Magnetic alloys, cemented carbides, catalysts, and driers for paints and inks each account for about 10% of U.S. cobalt use.

Historical cobalt consumption and the relative importance of purchased scrap are shown in figures 1 and 2. The sharp increase in scrap consumption in 1986 was the result of a change in the way the USBM collected data on cobalt scrap consumption rather than a sudden change in actual scrap use. Since that time, approximately 15% to 20% of U.S. annual cobalt consumption has been from secondary cobalt in the form of purchased scrap. In 1991, the United States consumed 7,238 mt of cobalt, of which 1,578 mt was recovered from purchased scrap. In that year, the United States imported 370 mt, gross weight, of cobalt waste and scrap valued at $3.9 million. U.S. exports of cobalt waste and scrap are reported in combination with exports of unwrought cobalt metal and metal powders.

Cobalt-bearing scrap is processed or used by a wide variety of industries, including some cobalt refiners, chemical and metal powder processors, consumers, superalloy scrap processors, and metals reclaimers. Falconbridge Ltd. is the only cobalt refiner that uses significant quantities of scrap. Secondary cobalt-bearing materials are smelted into matte at Falconbridge's smelter at Sudbury, Ontario. Matte from Sudbury is sent to Falconbridge's Nikkelverk refinery in Norway where electrolytic cobalt is produced. Union Minière S.A. and GTE Products Corp. are two examples of cobalt processors that use cobalt-bearing scrap. Union Minière processes refined cobalt metal, cobalt-bearing scrap, and residues to make cobalt metal powders and oxides at its Olen, Belgium, facility. GTE processes cemented carbide scrap into cobalt metal powder at its plant in Towanda, PA. Examples of consuming industries that use cobalt-bearing scrap include producers of superalloys, magnetic alloys, wear-resistant (hardfacing) alloys, steels, and cemented carbides. Superalloy scrap processors sort and treat scrap for sale to superalloy melters. Two U.S. metals reclaimers process spent petroleum catalysts to recover the various components, including cobalt as a mixed cobalt-nickel residue or alloy.

Sources of Secondary Cobalt: Cobalt-bearing scrap originates during various stages of alloy processing and/or product manufacturing. For example, superalloy scrap is generated by wrought and cast superalloy producers, forgers, and engine manufacturers. Some cemented carbide scrap is generated during the production of cemented carbide parts. Used cobalt-containing products are another source of secondary cobalt. Examples include superalloy scrap in the form of used jet engine parts, spent petroleum catalysts, homogeneous catalysts from the chemical processing industry, and used cemented carbide wear parts and tool inserts. Scrap from military bases, including cobalt-containing parts from maintaining or dismantling jet engines, is collected and sold by the Defense Reutilization and Marketing Service.

In alloy production, internally-generated and purchased scrap can represent a significant fraction of the raw materials supply. For example, melts for wear-resistant alloys are estimated to contain 37% scrap. Melts for cast and wrought superalloys are estimated to contain 55% and 60% scrap, respectively. In cemented carbide production, an estimated 30% to 40% of the cobalt consumed originates from cemented carbide scrap.

Recovery methods: In alloy-producing industries, internally-generated and purchased scrap are recycled at the melting stage complementing the use of primary metals. In addition to recycling to a similar alloy, cobalt-bearing alloy scrap can also be downgraded. Downgrading is the recycling of cobalt-bearing scrap to make an alloy with a much lower cobalt content. The cobalt may be diluted to the level of a residual element and does not contribute to the properties of the new alloy.

Cemented carbide scrap, such as used cutting tool inserts, wear parts, or dies, can be recycled by a wide variety of methods. It can be melted and recycled into wear-resistant alloys such as stellites, treated by chemical methods to recover individual components, or broken down by physical methods to produce powders ready for pressing into new cemented carbide parts. The zinc process is an example of an important physical method for recycling cemented carbides where cemented carbide scrap is first sorted by grade, then cleaned by washing or leaching to remove brazes, iron, or other impurities. The cleaned scrap is immersed in molten zinc, which alloys with cobalt and breaks the bond between the carbide particles and the cobalt binder. The zinc is removed by vacuum distillation, leaving a porous mass of carbide and cobalt that can be crushed and milled.

After adjusting the carbon content, the powder is ready to be used in the production of new cemented carbide parts.

Spent catalysts from the desulfurization of petroleum are sent to metals reclaimers to extract the individual components. The catalysts are first heat-treated to remove carbon, hydrocarbons, and sulfur. They are then leached and the resulting solutions are treated to separate the dissolved metals. A variety of leaching and metal separation methods are used today. Some metals reclaimers use both pyrometallurgical and hydrometallurgical processes to treat spent catalysts. In either case, cobalt and nickel are usually recovered together. The cobalt-nickel residues or alloys can be further refined to pure cobalt and nickel or, in some cases, sold as an additive to steel alloys.

Homogeneous catalysts are used in the production of terephthalic acid and dimethyl terephthalate. Once these catalysts are spent, cobalt-containing residues are returned to cobalt chemical processors to be reprocessed into new catalyst material.

The USBM has been involved in research on recycling cobalt-bearing scrap for over 30 years. This research includes laboratory studies on superalloys, magnetic alloys, hardface alloys, cemented carbides, and catalysts. The USBM-modified zinc process has become an important commercial method for recycling cemented carbide scrap. The USBM has also investigated various methods of scrap identification and worked with the U.S. Department of Defense on implementing these methods in Defense scrapyards. Alloy identification is an important first step in the sorting of various scrap alloys before recycling. Additionally, the USBM has studied the availability of cobalt-bearing scrap and the flows of cobalt-bearing materials in the United States.

Secondary products: Cobalt-nickel residues or alloys reclaimed from spent petroleum catalysts could be considered intermediate products requiring further processing.

Scrap Prices and Markets: Prices for cobalt-bearing scrap are not published. For a given type of cobalt-bearing scrap, demand and price depend on several factors, including the amounts and prices of cobalt and other metals present, the levels of residual and undesirable elements, the versatility of applications, the cost of processing, and availability. When cobalt metal prices are high, demand increases for cobalt-bearing scrap as a substitute for primary metal, and more scrap is recycled. Conversely, when metal prices are low, some cobalt-bearing scrap will not be recycled. For example, melt-shop smoke (flue dust and fume) from the superalloy industry is recycled when metal prices are high, but landfilled when metal prices are too low to make recycling economical. Strong demand for nickel can cause cobalt-containing nickel alloys to be downgraded to stainless steels.

Outlook: Recycling is well-established in many cobalt-consuming industries. Economic factors, such as metal prices and scrap collection and processing costs, will continue to influence whether cobalt-bearing materials are recycled, downgraded, or landfilled. Environmental factors, such as the cost of landfilling metal-containing wastes, may make recycling of more cobalt-bearing materials economic. This was the driving factor for the initiation of metals recovery from spent petroleum catalysts during the past two decades.

Technological changes will also impact recycling. Improvements in alloy processing methods to yield near net-shape products reduce the volume of manufacturing scrap generated. Improvements that extend the service life of products, such as cemented carbides, reduce the volume of post-consumer scrap generated. New methods of scrap processing may reduce the amounts of cobalt lost via downgrading or disposal of low grade and mixed-alloy scrap. However, in some products, such as many cobalt chemical applications, cobalt is present in such low quantities and dispersed in such a way that recycling or recovery are not expected to become feasible. For these reasons, the estimated percent of secondary cobalt consumed in the year 2000 is not expected to change significantly from the current 15% to 20%.

Figure 1.
Annual cobalt recycling
(Thousand metric tons, cobalt content)

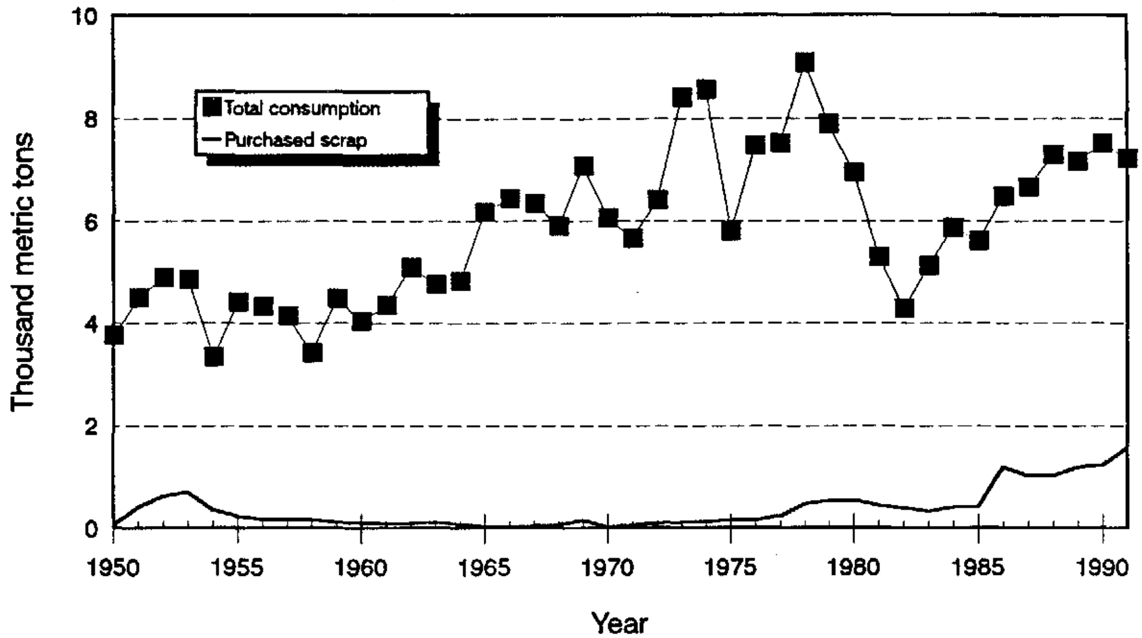
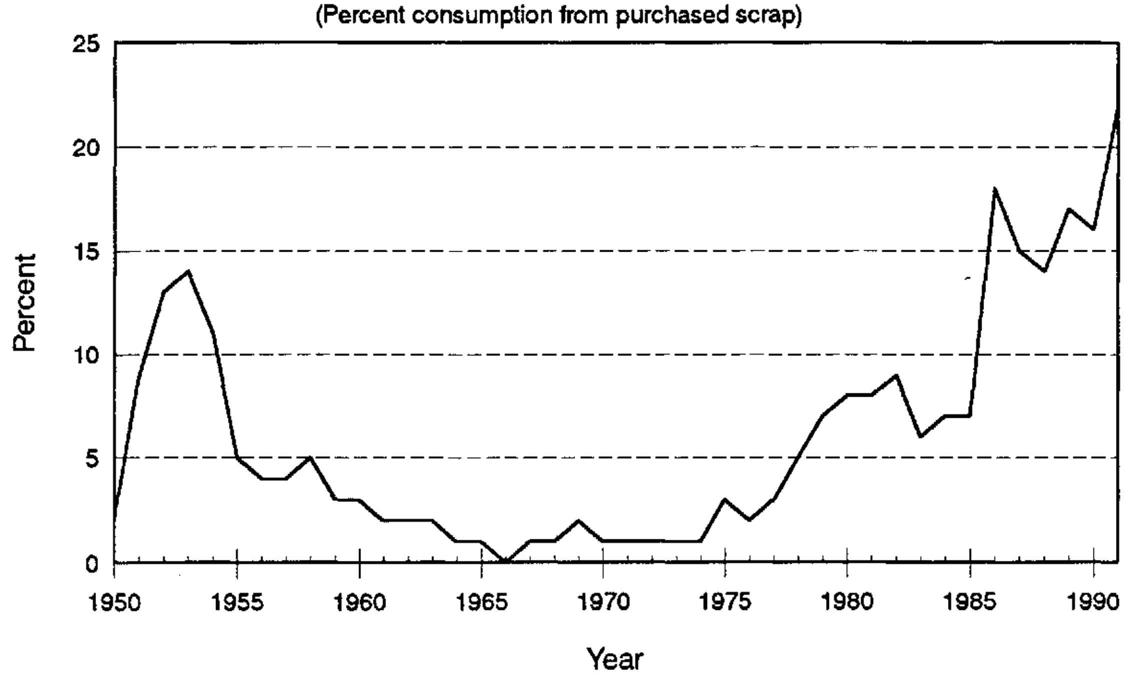


Figure 2.
Annual cobalt recycling
(Percent consumption from purchased scrap)



Cu

COPPER

by Janice L. W. Jolly

Salient Facts: Copper ranks third in world metal consumption after steel and aluminum. The major copper consuming nations or areas of the world are Western Europe (29%), United States (20%), Japan (15%), the C.I.S. (7%), and China (6%); an estimated 11 Mmt of primary and secondary refined copper was consumed in 1992. About 75% of the metal consumed in the United States was for electrical and electronic uses, finding widespread application in all sectors of the economy. Nonelectrical uses in the construction (11%), machinery (5%), transportation (5%), ordnance (2%) and other miscellaneous (2%) end use sectors make up the remainder. Copper and copper alloy powders are used for brake linings and bands, bushings, instruments, and filters in the automotive and aerospace industries, for electrical and electronic applications, for antifouling paints and coatings, and for various chemical and medical purposes. Copper chemicals, principally copper sulfate and the cupric and cuprous oxides, are widely used as algacides, fungicides, wood preservatives, copper plating, pigments, electronic applications, and numerous special applications.

In 1991, about 1.6 Mmt of copper-base scrap, containing an estimated 1.2 Mmt of copper, was consumed in the United States. Copper from old and new unalloyed and alloyed scrap was valued at $2.2 billion, and made up 44% of U.S. apparent copper consumption. About 20% of U.S. refined copper production was from scrap. Five secondary smelters and a small 450-ton-per-year secondary electrowinning plant had a combined copper capacity of 441,450 mt in 1991. In addition, about 28 ingot makers, 40 brass mills, and 750 foundries, chemical plants, and other manufacturers also consumed copper scrap in the United States. Most U.S. scrap is consumed at brass mills, smelters, and ingot makers. Wire rod mills, by contrast, consume 77% of the U.S. refined copper, and very little direct melt scrap.

Apparent Consumption of Copper, United States
(Thousand metric tons)

Consumption, by Type	1950	1960	1970	1980	1990	1991
Apparent consumption[1]	1,784	1,853	2,493	3,087	2,942	2,783
Old + new scrap, percent	50	43	45	48	45	44
Apparent consumption, industrial[2]	1,337	1,452	1,819	2,179	2,168	2,098
Old scrap, percent	33	27	25	28	25	25
Consumption, reported refined	1,292	1,225	1,854	1,862	2,150	2,058
Refined from scrap, percent	15	22	25	28	20	20

[1]Apparent consumption = primary production + old + new scrap + net imports + stock changes
[2]Apparent consumption calculation excludes new scrap.

The United States is one of the largest international sources for copper scrap. U.S. exports of copper scrap have been increasing since the 1960's, when the Far East nations began to industrialize. More recently, China has become a significant importer of U.S. copper scrap. Canada and Mexico are the leading sources for U.S. imports of copper and copper alloy scrap. U.S. copper scrap exports increased from 17,000 mt in 1950 to 248,000 mt in 1991. In 1991, U.S. scrap exports were valued at $ 446.4 million, while scrap imports were valued (C.I.F.) at $124.9 million.

Sources of Secondary Copper: The Institute of Scrap Recycling Industries, Inc. (ISRI) recognizes about 53 classes of copper and copper alloy scrap. Although there are several grades within each, the major unalloyed scrap categories are No. 1 copper (common names — Barley, Berry, Candy, and Clove), which contains greater than 99% copper and often is simply remelted, and No. 2 copper (common names — Birch, Cliff, and Cobra), which usually must be re-refined. In addition to the many copper and copper alloy scrap types, there are many special types such as skimmings, ashes, and residues, which contain 12% to 30% copper; and others of lower copper content, such as electronic scrap, refining slags, printed circuit and other clad materials, and metal-laden waste liquors.

In 1991, the major copper scrap types consumed were: No. 1 copper, 28%; No. 2 copper, 22%; leaded yellow brass, 16%; yellow and low brass, 6.8%; automobile radiators, 5.7%; red brass, 4%; cartridge cases, 3.6%; and low-grade ashes and residues, 9%. A wide variety of alloys made up the remaining 5%. Brass and copper tube mills processed 66% of the No. 1 copper and most of the cartridge cases and yellow brass, while the secondary smelters and ingot makers processed 89% of the No. 2 scrap and most of the auto radiators and red brass scrap.

Principal Scrap Source Materials and Form of Recovery
(Thousand metric tons, copper content)

	1950	1960	1970	1980	1990	1991
New scrap:						
Copper-base	440	396	664	804	751	658
Aluminum-base	6	5	10	20	23	22
Nickel-base	0.2	0.1	0.1	0.2	.04	.05
Zinc- & tin-base	<.01	.03	.01	.02	--	--
Total	446	401	675	824	774	680
Old scrap:						
Copper-base	437	387	453	596	502	495
Aluminum-base	2	2	4	15	33	38
Nickel-base	1	0.5	0.7	0.1	.08	.06
Zinc- & tin-base	.09	0.08	0.04	0.1	.03	.02
Total	441	390	458	613	536	533
Total Scrap	887	791	1,133	1,437	1,310	1,213
Form of recovery:						
Unalloyed copper	236	272	474	534	450	426
Copper alloys	617	490	631	850	801	725
Aluminum alloys	15	14	23	47	55	59
Chemicals	16	12	2	3	3	2
Iron-Steel alloys	2	3	3	2	.6	.06
Other alloys	0.3	0.2	.01	.02	.01	.01

Recycled copper is derived 56% from new scrap and 44% from old scrap. Purchased new scrap derived from fabricating operations yielded 679,882 mt of contained copper, 75% of which was recovered at brass mills. Smelters and refiners recovered 36%; ingot makers, 11%; brass mills, 49%; and miscellaneous manufacturers, foundries, and chemical plants, 4% of total copper in copper-base scrap in 1991. In addition, nearly 60,000 mt of copper was derived from aluminum-,nickel-, and zinc-base scrap. A manufacturer may generate up to 60% scrap as clippings, trimmings, stampings, borings, and turnings when processing copper and copper-base products into finished articles. This new, or mill-return, scrap is readily used by brass and copper tube mills to generate new semifabricates. Secondary materials that require minimal processing are commonly called direct melt scrap. In the United States, direct melt scrap provided about 795,400 mt or about 66% of copper from all secondary materials in 1991.

Since World War II, the ever-increasing reservoir of copper products in use, much of which is eventually recycled as old copper, has provided annually between 19% and 33% of U.S. apparent industrial consumption, and on average, has provided about 18% of world copper consumption. The U.S. industry's contribution to the secondary materials reservoir of items in use, or abandoned in place, over the same period has increased from about 16.2 Mmt in 1940 to around 69.8 Mmt. This secondary materials reservoir does not include a sizeable and growing pool of new scrap that is recycled every year. New scrap currently makes up about 24% of U.S. apparent consumption of copper; copper in old and new scrap comprises about 44% of consumption. In 1940, the world copper reservoir of copper materials in use, or abandoned in place, was about 32.9 Mmt by 1991, this reservoir of potentially recoverable secondary materials exceeded 188.9 Mmt of copper.

The annual U.S. contribution to the unrecovered copper reservoir of items in use, or abandoned has been increasing since 1983 at the rate of about 1.2 Mmt per year. Of this amount, over one-half of the unrecovered copper remains in the consumer and general use sectors. Copper that is not recovered may be placed in one of three categories: (1) still in use and unaccountable, (2) solid waste disposal, (3) dissipated and lost. Copper is one of the most recycled of metals, but still much would appear to be entering solid waste disposal sites; the amount has been estimated as high as 50% of the unrecovered products. Copper has few applications that are dissipative by nature; only about 0.5% of total copper consumed may be lost and unretrievable such as copper used in chemicals.

The availability of secondary copper is linked with the quantity of products consumed and their life cycles, or duration. Many estimates have been made about individual products; product lifecycles may even vary from country to country, according to construction methods and concepts. However, copper in electrical plants and machinery averages 30 years; in nonelectrical machinery, 15 years; in housing, 35 years; and in transportation, 10 years. The average useful life for copper products is about 25 years, before being scrapped and entering the market as old scrap. New (manufacturing) scrap, on the other hand, has a short life of about 30 days, and its recovery is limited by domestic manufacturing rates and efficiencies. This wide difference in turnaround and availability has resulted in a gradual increase of new scrap versus old scrap as a component in all scrap collected in the United States. The rate of old scrap recovery is limited not only by copper's long life and its essential uses, but also by the sensitivity of scrap collection to market prices.

Recovery Methods: Because scrap is a bulky material, the customary practice is to bale light scrap and cut heavy scrap to size so that it can be handled. An important copper recycling material is cable scrap. Whereas previously burning of the cable to remove the plastic parts was acceptable, this is no longer always possible, or desirable. Thus, mechanical dismantling of the cables is common practice through cutting, granulating, and use of various metal separation techniques to separate the plastics and fluff from the metal.

Most old scrap must be reprocessed by either smelting and refining, or by leaching and electrowinning to form a pure copper product. Fire refining in a reverberatory or other furnace may be sufficient for the better grades of scrap. The fire-refining process uses oxidation, fluxing, and reduction to produce refined ingot, wire bar, slab, or billet. For higher grades of refined cathode, however, the poorer grades of scrap must be first smelted with various fluxes, poled to remove oxygen, and then cast into anode form for further processing in an electrolytic refinery. Byproducts, such as tin and precious metals, may be retrieved during the preliminary procedures of smelting, or during refining from the tankhouse sludges. Other impurities, such as iron, lead, arsenic, and antimony may be removed in the slag by fluxing. Reverberatory or electric rotary melting furnaces are used for casting various copper forms, such as slabs, cakes, or billets. Asarco shaft furnaces may be used with holding furnaces in conjunction with continuous casting systems.

Processing complex copper-containing materials, such as drosses, flue dust, catalysts, collector dust, slimes from electroplating waste water, and metal-rich slags from converter processes requires versatile production processes. Most processing plants have built-in water recirculation systems in which some of the metal content is recaptured and reused. Many of these wastes must be treated for metal recovery. In general, a combination of various hydrometallurgical techniques such as precipitation, cementation, ion exchange, solvent extraction, reverse osmosis, gaseous reduction, and electrolysis are used. Cementation has been successfully employed to recover copper from waste effluents. Solvent extraction and ion exchange are highly selective methods for separation of copper from other common metals in solution. Mechanical and thermal dismantling, and more recently, leaching and solvent extraction and electrowinning procedures have proved effective in treatment of certain types of electronic scrap. Electrowinning recovery is also used for waste processing fluids that contain copper and other metals. A low-grade copper cathode, copper sulfate, copper oxides, copper precipitates, and byproduct metals can be produced through this method.

Black copper (75% to 80%) copper) is the principal product of the blast furnace and still contains some iron and zinc along with most of the tin, lead, and nickel of the charge. Traditionally, this material is refined in a scrap converter, which is of a more modest size than its primary cousin; also, coke is added liberally to the charge, adding extra heat and providing a mildly reducing condition, thus facilitating removal of zinc, tin, and lead in the gas stream. A copper anode is poured for final refining in an electrolytic tankhouse.

Scrap Prices and Price Sources: Prices paid for scrap are related generally to the current refined copper price, but the spread between the two prices must be sufficient to allow for processing costs and the inherent costs of scrap preparation (collection, sorting, shipping, chopping, briquetting, etc.). The terms that scrap smelters can charge for processing becomes uneconomic as the gap between scrap and refined price narrows. The spread between refiners buying price for No. 2 scrap and the producers refined copper price has varied from 9 cents in 1970, 27 cents in 1980, to 21 cents in 1991. The low spreads in the early 1970's were caused by price controls placed on U.S. copper during this period. The very high spreads of the late 1980's, which averaged above 30 cents per pound as shown in Figure 1, were the result of high refined copper prices and a good supply of scrap. Price spreads also tend to widen when speculative interest is active on the exchanges, such as is the case when the copper price is high. The spreads have been decreasing since the high point of 1987, as a result of lower refined prices.

Copper scrap prices are generally published in such sources as the daily *American Metal Market* and weekly *Metals Week* in the United States and the weekly and monthly *Metals Bulletin* of the United Kingdom. Both dealers' and buyer's scrap prices may be published. Brass mill and refiners No. 1 and No. 2 scrap categories are those most often quoted. Brass mill buyer's No. 1, bare bright, is the highest scrap category price.

World Review: The Western European countries make up the largest single market for scrap in the world. Germany, Italy, France, and the United Kingdom are the leading consumers. The United States is second after the European Community (EC) in total scrap consumption. Asia, mostly Japan, is the third largest scrap consuming area of the world. Copper scrap accounted for 36% of annual copper consumption in the countries of the EC, compared with about 42% of total annual copper consumption in the United States. In recent years, about 21% of refined copper in the United States and 40% of the refined copper produced in Western Europe was derived from copper scrap. On average, copper from scrap accounts for about 18% of the world's refined copper production.

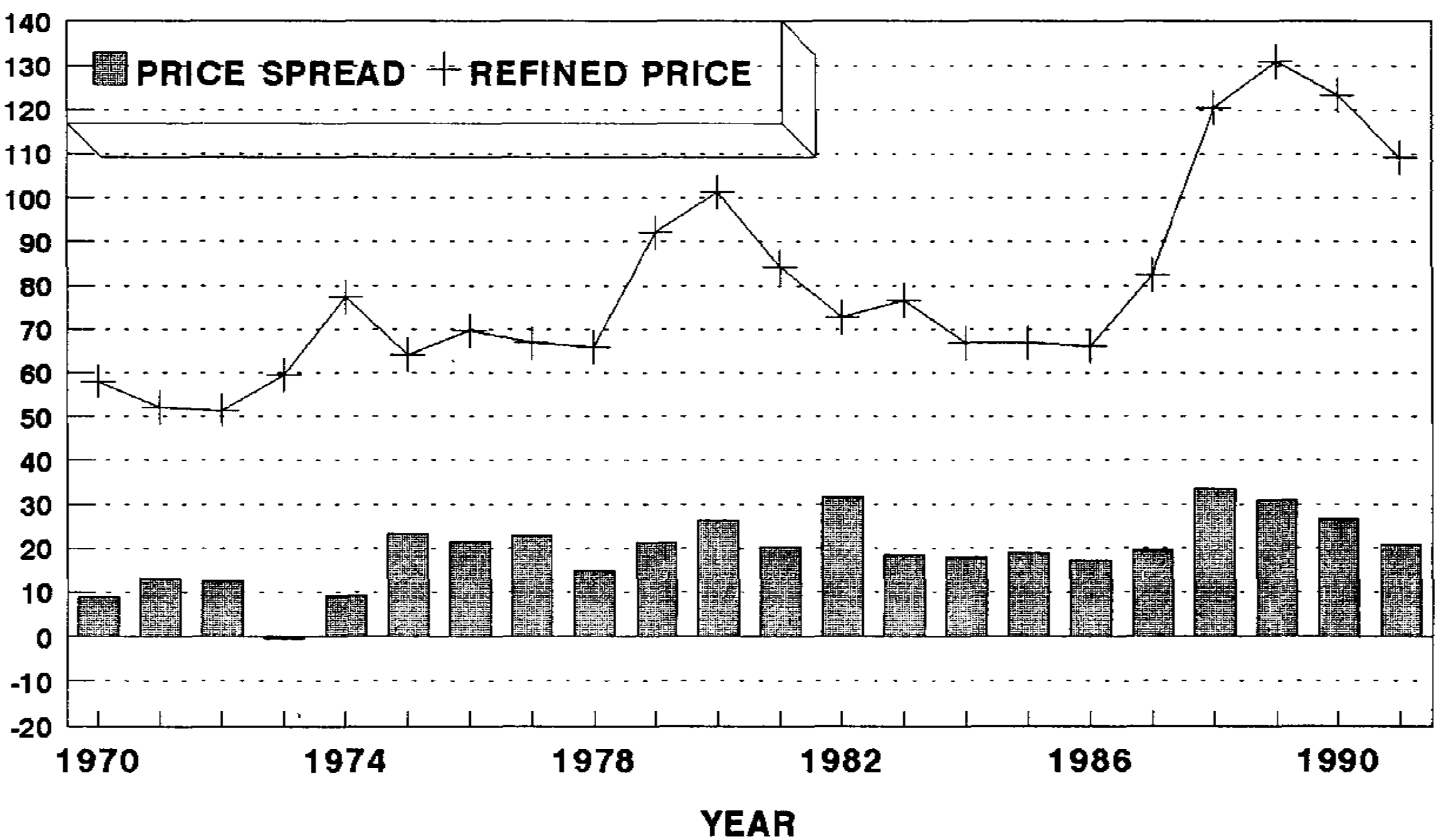
As shown in figure 2, the United States is the largest exporter of copper scrap in the world, followed by France, Germany, and the United Kingdom. The EC, as a group, makes up the largest single scrap trading area in the world. Nearly all imports and exports from the EC are to or from other European nations. The Asian countries export very little scrap, and most of this goes to other Asian countries. Asian imports of scrap from Western countries has grown significantly in recent years. China, in particular, has increased its imports of U.S. generated scrap over the past 3 years.

Outlook: Over the next decade, copper scrap will continue to be a premium material for the U.S. semifabricating industry. Because scrap is usually a lower-cost alternative to primary metal, it will continue to be of great interest to Far Eastern countries as they expand their industries. Recovery of copper from the large and growing reservoir of copper products in use may be limited by the following factors: (1) copper prices, (2) life of products, (3) available recovery technologies, and (4) rate of copper consumption. Affecting the availability of new scrap is the recent industry observation that the amount of new scrap being generated by manufacturing plants has been cut by as much as 50%, owing to increased production efficiencies. Another factor that will affect copper scrap is collection, use, and processing over the next decade is the limitation on lead in copper plumbing alloys, as a result of legislation limiting the content to 2% lead or less.

Without successful implementation of new recovery technologies, the recovery of copper in all parts of the economy will be impeded by increased legislative requirements. New technologies, some of which have been introduced, are expected to increase recovery of copper from waste waters, electronic scrap, and other scrap with low copper content. With increased environmental and labor safety requirements, some types of ingot will be difficult to produce economically. New technologies will be required to decrease the lead content of machinable and other leaded-copper alloys.

World consumption of copper in scrap was estimated to be 5 Mmt in 1991, and is forecast to be about 7.2 Mmt by the year 2000. Of this amount, 1.8 Mmt in 1991 and 2.8 Mmt in 2000 will be as secondary refined copper.

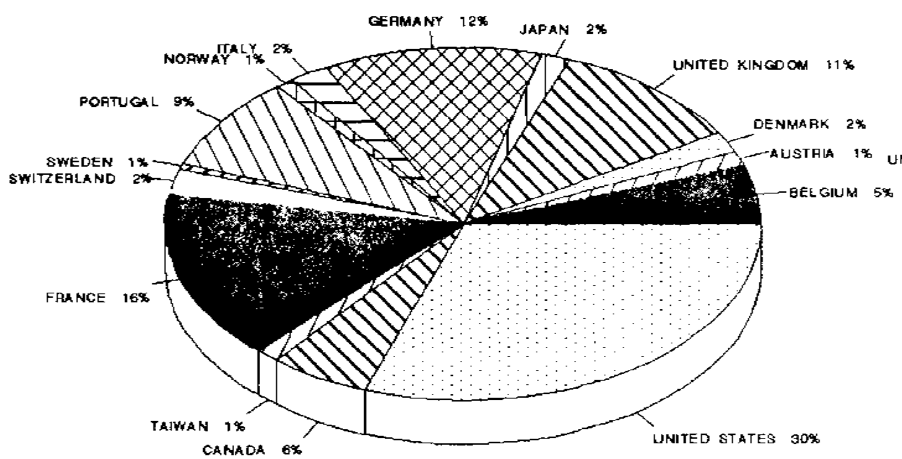
Figure 1.
Price spread trends between no. 2 scrap[1/] and U.S. producers' refined copper prices



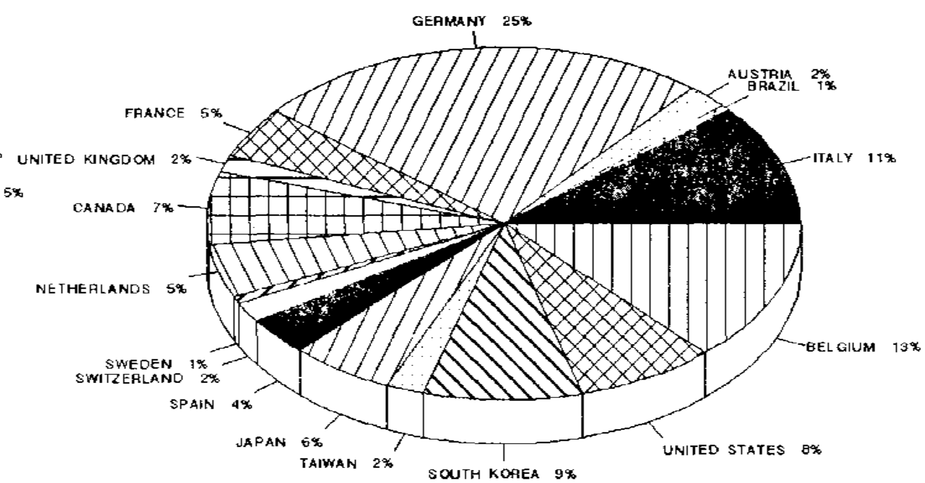
Sources: American Metal Market (scrap) and Metals Week (refined)

[1/] Refiners buying price for #2 scrap.

Figure 2.
World copper scrap trade in 1989 [1/]
Percent, by country shown



COPPER SCRAP EXPORTS
(1.2 million tons, gross weight)



COPPER SCRAP IMPORTS
(1.5 million tons, gross weight)

Sources: WBMS and Metallgeselschaft
1/ Complete trade data are not available for 1990 and 1991.
Eastern Europe, China, and India are not included.

Au

GOLD

by John M. Lucas

Throughout history, gold has been treasured for its beauty and permanence. Gold lore and the use of gold predates written history, and the mystique and folklore associated with gold has been a part of the fabric of civilized society throughout history. Similarly, the search for gold has stimulated world exploration and trade for more than 60 centuries.

Most of the newly refined gold that is fabricated today goes into the manufacture of jewelry. However, because of its superior electrical conductivity, resistance to corrosion, and other desirable combinations of physical and chemical properties, gold also emerged in the late 20th century as an essential industrial metal. Gold performs critical functions in computers, communications equipment, spacecraft, jet aircraft engines, and a host of other products.

In recent years, domestic or U.S. commercial-grade refined gold was produced by about two dozen companies. A few dozen companies, out of several thousand companies and artisans, dominated the fabrication of gold into useful products. Nearly all jewelry manufacturing was centered in the New York, NY, and Providence, RI, areas. Reported uses in recent years were as follows: jewelry and arts, 67%; industrial (mainly electronic), 26%; and dental, 7%. Although gold is important to industry and the arts, it also retains a unique status among all commodities as a long term store of value. It was, until recent times, considered essentially a monetary metal, and most of the bullion produced each year went into the vaults of Government treasuries or central banks.

In 1991, nearly 160 mt of refined gold were recovered by domestic refiners from both old and new scrap materials. The value of this production in terms of refined metal was nearly $2 billion. During the same period, secondary unrefined gold-bearing materials valued in excess of $1.16 billion were exported, principally for refining to commercial-grade gold. The principal recipient nations were Canada, France, Switzerland, and the United Kingdom. Similar materials imported by domestic refiners during 1991, and originating in Canada, the Dominican Republic, France, Switzerland, and elsewhere, were valued at nearly $200 million.

The USBM maintains nine research center throughout the Nation, and most conduct research into various aspects of extractive metallurgy that may be applicable directly or indirectly to the recovery of gold from secondary sources. Over the past two decades the Bureau has published numerous reports summarizing the results of research on the recovery of secondary gold.

Salient Gold Statistics, United States
(Metric tons)[1]

	1950	1960	1970	1980	1990
Reported consumption[2]	87	93.9	185.8	100	118.1
Secondary production[2],[3]	32.7	21.8	86.5	67.9	48.6
Secondary production as					
a percent of consumption	38	23	47	68	41
U.S. trade in secondary materials[4]					
Imports	NA	NA	NA	6.2	4.3
Exports	NA	NA	NA	41.1	166.9

NA Not available
[1]The troy system of weights is generally used in the United States for gold and other precious metals; however, to aid in harmonizing world data collection, Government practice now dictates the use of the metric system of measure.
[2]Estimated by the U.S. Bureau of the Mint, 1950-74, U.S. Bureau of Mines, 1975 to present.
[3]Old scrap and new scrap undifferentiated, 1950-70, old scrap, 1980-90.
[4]Source: U.S. Bureau of the Census.

Sources of secondary gold: Because of its high intrinsic value, gold has been recycled throughout the ages. Thus, a modern article of jewelry containing recycled gold could conceivably contain atoms of gold from a golden earring worn by Helen of Troy or from a nugget of gold used in the 4th millennium B.C. to barter for ingots of crude copper or other goods at a Mediterranean seaport. Gold's high rate of recyclability is further illustrated by the fact that virtually all of the gold ever mined can be more or less accounted for. Of an estimated 109,000 mt mined from historical times through 1991, only about 15% is believed to have been lost, used in dissipative industrial uses, or otherwise unrecoverable or unaccounted for. The remaining 85% is accounted for as official stocks held by central banks or privately held as coin, bullion, and jewelry. The mined total, about two-thirds of which was mined over the past 60 years, is equivalent in volume to a cube roughly 18 meters on a side. The Republic of South Africa has been a source of about 41% of the total.

Precious-metals refiners throughout the world recover gold from scrap. In the United States, about 60% to 80% of the scrap comes from current manufacturing operations, and the remainder comes from old scrap in the form of items such as discarded jewelry and dental materials, used plating solutions, junked electronic equipment, etc. Other recyclable materials routinely accepted by refiners include gold-bearing slimes, solutions, sludges and precipitates from base or precious metals smelters and refiners, old gold coins and medals, and dishoarded, low-purity and nonaccredited gold bars.

Many gold consumers or manufacturers have elaborate collection systems for reclamation of gold scrap resulting from the manufacture of gold items. Recycling also applies to all materials which may have come into contact with gold during processing and handling. Gold is so valuable that even the gloves, aprons, and dust masks worn by gold workers and the dust, or sweeps, from their shops may be collected and processed to yield payable quantities of metal. Similarly, a specialized field of secondary gold recovery focuses on gleaning gold from defunct gold processing operations.

Refiners receive scrap in a variety of forms and determine processing steps according to batch size, average gold content, and the impurities to be separated. A metric ton of manufacturer's electronic and computer scrap, for example, may yield nearly 1 kg of gold and 2 kg of silver. Scrap dealers and semirefiners may process the scrap to remove valueless constituents and then ship the upgraded product elsewhere, including overseas, for further treatment and refining. Although most domestic scrap processors are located in the Northeastern States, collection sites, semirefiners, and dismantlers of gold-bearing electronic devices are located nationwide. Scrap is either purchased outright or treated on a toll basis.

A considerable quantity of scrap is generated in manufacturing operations, but because of tight security controls over secondary materials in precious-metals plants, nearly all of this new scrap, or home-generated scrap, is recovered. Some old scrap, on the other hand, is lost because in practice gold cannot be economically recovered from all manufactured products; this is increasingly true as miniaturization of gold-bearing electronic products proceeds. The U.S. Department of Defense (DOD) recovers a significant quantity of gold from military scrap; other Federal Government agencies either participate in the DOD recovery program or have their own.

According to Gold Fields Mineral Services Ltd. (London), the supply of gold recovered from old gold scrap in the market economy countries during 1991 amounted to nearly 410 mt or 13 million troy ounces. Of this total, the Middle Eastern nations contributed nearly 150 mt; this compares with the previous year when distress selling of old gold jewelry during the Persian Gulf War swelled the total to over 180 mt. The nations which make up the Indian sub-continent and Far Eastern regions were, respectively, the second and third largest sources of old gold scrap to the market.

The Recovery Cycle: The features generally attributed to the metals recycling industry, high volumes of low-value metal, are quite unlike those which characterize the recycling of precious metals. The precious metals recycling sector deals largely with relatively low volumes of highly-valued raw material. Thus, unlike the high volume sector, proper handling, accountability, and security against loss and theft during generation, collection, and distribution become important additional burdens not generally shared with others in the industry.

The inherent high intrinsic value that may be contained in shipments of scrap to a smelter-refiner dictate that special precautions must be taken to assure that the payable content of each shipment is carefully maintained. A collection of raw electronic scrap, for example, may begin the recycling process by undergoing disassembly or shredding and separation of the precious metals-bearing components from less valuable components such as plastics and ferrous and base metals. This process, sometimes known as semirefining, may involve one or more companies and may entail the movement of many small shipments from collection points throughout the Nation or overseas. The end product of the semirefining sector is a small volume of high-value material concentrated from a large volume of low value scrap.

At the higher end of the spectrum of value, scrap generated during the manufacture of karat gold jewelry, for example, will probably go directly from the manufacturer to the smelter-refiner. Scrap originating at the manufacturing jeweler for example, is closely monitored by the company from generation through collection, packaging, and transportation to the recovery plant. The preceding examples, of course, illustrate only a small part of the wide variety of scrap forms which typically cross the loading dock at a smelter-refiner. Depending upon the capabilities of the smelter-refiner, receipts of individual shipments may range from large volumes of very low-grade precious metals-bearing material such as sweeps and spent plating solutions to small containers of high-grade karat gold scrap. In addition to work orders negotiated between the customer and the refiner, each shipment may also be accompanied by documentation ranging from title, insurance, and customs documents to licensing and transport documents addressing local, State, and national environmental and other regulatory requirements.

Generally, each refining transaction is negotiated individually between the refiner and the customer. Standard printed refining schedules or outlines of services, capabilities, and charges are usually used by smelters-refiners to establish the basis upon which the negotiations proceed. Factors considered during the negotiations include the type, size, quality, and character of the product to be refined. Other factors may include minimum or standard treatment charges, charges for preparation and assaying, charges or penalties for the presence of deleterious elements, and instructions regarding the basis for payment, etc. The customer may elect to sell the material outright, have the scrap refined and gold prepared to contract specifications and returned, or the customer may elect to draw an equivalent value of refined metal from a pool account established by the refiner.

Upon arrival at the smelter-refiner, individual shipments are assigned a control number. Each shipment or lot is then weighed, evaluated, and subjected to a variety of preparatory processes depending upon its particular character. Preparation may include incineration, roasting or melting, pulverizing, shredding, or grinding to produce a homogeneous product from which one or more representative samples are drawn. At this point, assays determine the character and content of the original shipment.

Following settlement, the refiner may combine similar lots to form large batches. Each batch is then introduced into the refining process, which may include pyrometallurgial, hydrometallurgical, and/or electrochemical processes, to separate or part gold from associated impurities and other elements. The extent to which the refining process may proceed depends upon the level of purity or fineness desired for reentry into the market. Products derived from secondary materials may range from bars of pure gold, various alloyed refinery and mill shapes such as sheet gold, wire, tubing, foils, leaf, and casting grain, to gold plating solutions and compounds and various gold-bearing organometallic liquids and conductive inks and pastes.

Outlook: The historic and universal recognition of gold as a highly valuable or precious metal, assures that virtually every conceivable source of recyclable metal will be used to both recapture the value inherent in the metal and to meet the continuing demand for finished metal in the market. Although price considerations may exert a powerful influence on the rate at which recyclable material returns to the market, industrial gold consumers (the principal source of supply), for reasons of security or prudent business practice, may be expected to keep their gold-bearing scrap moving into the market on a more or less established routine basis.

Private individuals, on the other hand, may rapidly hoard or dishoard metal in response to the prevailing or anticipated economic or political climate-hoarding coins, bars, and jewelry as a hedge against inflation or in anticipation of economic or political upheaval, etc., and dishoarding during periods of relative stability when alternative, dividend-paying investments may be more attractive. Most of the conditions and incentives which have encouraged high rates of gold recycling in past years still, more or less, exist today and will probably exist into the future. Gold, probably more than many other recyclable materials, will continue to be a highly sought-after commodity in the world's secondary metals market for many years to come, especially if the world population continues to grow at current rates thereby steadily diminishing the tiny per capital fraction available from other sources.

During the 10-year period from 1982 through 1991, old gold scrap, as estimated annually by Goldfields Mineral Services, ranged from a low of 13% of the total world supply to a high of 22%; the average was 16%. Barring any unforeseen changes in the established pattern of world secondary refinery supply, the quantity of gold derived each year from secondary sources is forecast to approximate the annual percentages derived over the past decade. Developments which may serve to increase the percentage of scrap entering the market during the remainder of the decade include the following: (1) any decline in world gold mine production, if not offset by refined supplies from other sources such as central bank sales or disinvestment from the private sector, could lead to higher prices and thereby coax more material into the recycling stream, (2) the establishment of more efficient, centralized scrap collection and recovery centers, especially in the jewelry-producing nations of the Middle and Far East, could encourage higher rates of recycling, and (3) continued growth in the demand for gold jewelry in rapidly industrializing nations, such as those of the Far East and China, could result in increased recycling of older-style jewelry as fashion tastes evolve with improved standards of living. Absent a dramatic increase in the world price of gold, recycling in the nations of the Western World will probably remain more or less within the levels established during the past decade.

Fe

IRON AND STEEL

by Gerald W. Houck

Salient Facts: Iron is the most widely used of all the metals. In 1990, the iron and steel shipments in the United States consisted of steel mill products (90%), iron castings (9%), and steel castings (1%). Iron and steel products make up about 75% of the weight of an automobile. Steel is widely used in building, highway, industrial, and all other forms of construction. Industrial machinery and tools, as well as hand tools and equipment are produced from steel. Electrical machinery is primarily steel. Steel products are used for containers and packaging, for conveyance of all types of fluids, and for a host of products from very small, such as hypodermic needles and paper staples, to very large, such as bridges and giant pieces of equipment.

As shown in figure 1, consumption of steel mill products and steel and iron castings in the United States amounts to about 100 Mmt/yr. Each year, over 50 Mmt of scrap iron and steel are recovered and recycled into new products. About 80%, or 40 Mmt, is recycled at steel mills and foundries in the United States; about 20%, or 10 Mmt, is exported for recycling in other countries. As shown in figure 2, this represents over 50% of total consumption, an increase from the 35% to 40% recycling rate during the 1960's. In addition, steel mills and foundries recycle scrap generated within their own plants, which amounts to about 20 Mmt/yr.

A major industry exists to collect such a vast amount of scrap and prepare it for recycling. Over 5,000 individual establishments, located throughout the country, purchase steel from individuals and businesses and prepare it to specification for consuming mills and foundries.

Sources of Secondary Iron: All iron and steel is recyclable. Some steel, however, is used in applications that do not allow for economical recovery. Much of the steel is used in long life applications; as a result, there is a vast reservoir of steel and iron in service that will some day be available for recycle. Prompt industrial scrap from manufacturing facilities that fabricate steel products is the most important source of recycled iron. Junked automobiles are the largest source of obsolete or post-consumer scrap. Demolition of steel structures is another important source. Railroad companies provide a steady flow of scrap from their fabricating shops as well as from the recovery of wornout or abandoned track and old railroad cars.

Recovery methods: Iron and steel scrap is recycled by remelting and casting into semi-finished steel forms or castings. Producers of steel mill products use basic-oxygen furnaces (BOF) or electric furnaces. The proportion of scrap in the metallic charge to a BOF is limited to a maximum of about 28%, of which about one-half is normally home scrap, leaving the capability to consume from purchased scrap only about 14% of the total input. Electric furnaces are remelting devices only and are able to produce steel from a 100% scrap charge; the availability of suitable scrap may, however, require the addition of virgin iron in the form of pig iron or direct-reduced iron in electric furnaces.

Steel foundries use electric furnaces and iron foundries use electric furnaces or cupolas. A cupola is a shaft furnace that uses coke as the principal fuel; the charge can be 100% scrap, but cast iron scrap must be a large percentage of the charge if no pig iron is used.

Although BOF's are used to produce about 60% of the steel in the United States, much more scrap is melted in electric furnaces than in any other type of furnace. In 1990, well over one-half the scrap recycled in the United States was melted in electric furnaces.

Alloys, Coatings, and Residuals: In addition to iron, all steel contains small amounts of carbon and manganese. About 90% of all steel produced is carbon steel, which may contain small amounts of elements other than iron, carbon, and manganese to provide specific physical properties. Other categories of steel are alloy steel and stainless steel.

Most alloy steel contains chromium, molybdenum, or nickel, or some combination of these elements to establish desired properties. Other alloy steels are electrical steel, which contains silicon and has very low electromagnetic energy losses when used in transformer cores, and tool steel, of which there are many varieties containing some combination of chromium, vanadium, tungsten, cobalt and molybdenum.

Stainless steel contains at least 10.5% and usually 18% or more chromium. Most stainless steel also contains from 6% to 11% nickel; some stainless steel contains from 1% to 3% molybdenum.

Some steel products have metallic or other coatings, and are often painted or coated after fabrication. The most common coating used on steel products is zinc. Others are tin, aluminum, terne (an alloy of lead and tin), and chromium. The base steel for coated products is normally carbon steel.

When steel is recycled, care is taken to charge alloy steels containing recoverable elements into new steel of same or similar alloy composition in order to take advantage of alloying elements contained in recycled metal. When recycled scrap is not sorted by alloy type, alloying elements are retained as unwanted elements, or residuals, in product. The coating elements zinc, aluminum, and lead are vaporized or oxidized in the high temperature of the steelmaking process and are removed with the dust or the slag. EPA regulations require that electric arc furnace dust be handled and disposed as hazardous waste because it normally contains unacceptable levels of lead, cadmium, and chromium. Zinc can be recovered and recycled from the dust produced by steelmaking shops that process large volumes of zinc-coated scrap. Regulations require processing the dust for recovery if it contains 15% or more of zinc.

Steelmakers must take great care in purchasing and selecting scrap to assure that the amount of residuals does not exceed an acceptable level, which varies according to the product being produced. In general, sheet steel products that will be extensively cold formed, and rod products that will be cold drawn require the lowest levels of residuals; electric furnace steelmakers who produce these products by remelting scrap have found it necessary to dilute their scrap with residual-free virgin material such as pig iron or direct-reduced iron in order to produce steel with an acceptable level of residuals. Producers of products that have high strength but do not require a high level of ductility—steel reinforcing bars for concrete is an example—can accept a higher level of residuals in their products; these producers often seek scrap containing higher residuals because it can be purchased for a lower price.

Scrap preparation: Scrap recycling facilities collect, accumulate, sort, and prepare scrap according to specification for delivery to steel mills or foundries. There are about 5,000 ferrous scrap recycling establishments in the United States. Most are quite small, but many are large, corporate-owned, industrial facilities with dozens or even hundreds of employees and the capability to collect and process large amounts of scrap. Preparation involves sizing of the material as required for charging into remelting furnaces, as well as sorting and selection of scrap to take advantage of alloy content and to control residual content.

Major types of sizing equipment used in recycling facilities are shredders, shears, and balers. Shredders have become the most recognized equipment of the scrap processing industry. Shredders reduce whole automobiles to small (typically fist-size) pieces. Appliances and other types of unprepared scrap may also be shredded. Shredded material is processed to remove and recycle nonferrous metals, such as copper, zinc, and aluminum, as well as to remove nonmetallic materials, such as glass, plastic, and rubber. The resultant product, known as shredded scrap is well accepted as a steelmaking raw material both domestically and for export.

Shears are used to cut large pieces of scrap to size as required for charging into steel furnaces. Shearing is generally used to prepare heavy pieces that, once sheared, can be easily handled and charged.

Balers are used to compact light material into rectangular bundles that can be easily handled and charged. Bundle size is established by agreement between the processor and the customer.

Except in the largest cities, virtually all automobiles that are junked pass through an automobile dismantling operation before being sold to a shredder operator. The dismantler removes any salable parts from the car, including reusable parts and readily removable nonferrous metal scrap parts. Examples of salable nonferrous metal scrap are the battery, radiator, heavy copper parts such as the alternator, and the catalytic converter, which contains recyclable precious metals. Most shredders require that gasoline tanks, tires, and undeployed airbag modules be removed from all cars, and, of late, require that the refrigerant be exhausted from air conditioning systems. A shredder operator may have other requirements that must be met; some shred only cars from which engines have been removed. After removing salable parts, dismantlers usually flatten cars to increase the number that can be transported in a load. Steel gasoline tanks are drained and sold for baling and recycling.

Large automotive and appliance steel stamping plants often have their own equipment to prepare scrap. This normally consists of a collecting system, baler, and loading facilities for trucks or railroad cars for direct shipment to steel plants. Smaller plants place scrap in containers that are removed by the scrap recycling facility that buys the scrap. Scrap generators and recycling facilities cooperate to prevent unintentional mixing of different types of scrap, thereby realizing highest possible value for scrap and providing consistent supply to the ultimate purchaser, the steel mill or foundry.

Demolition of steel buildings and industrial plants is a significant source of recycled scrap. Demolition contractors often have mobile equipment, such as hydraulic shears, that enables scrap to be prepared on the demolition site, for transportation direct to a consuming mill.

Municipal solid waste contains as much as 10% steel, consisting primarily of used steel or bimetallic (steel body-aluminum lid) beverage cans and steel food cans. The steel is mostly tin plate. Many municipalities separate the steel and bale it for recycling. Another option is to shred the cans and sell the material to a detinning facility for recovery and recycling of the tin. The resulting steel product is baled and has a higher value to a purchasing steel mill because of its lack of potential residuals.

An important function of scrap recycling facilities is delivery of selected and prepared scrap to steel mill or foundry according to schedule; this reduces the total amount of handling of the scrap and minimizes the mill or foundry's investment in idle inventory.

USBM Research: To conserve natural resources and reduce imports by developing new technology to recover materials from scrap, residues, and effluent is an objective of the USBM Minerals Research program. For example, ferrous scrap from automobiles contains copper and tin as major impurities. If these elements could be removed from the scrap, it would avoid the loss of the impurity metals and increase the value of the scrap that is being recycled. The USBM is investigating possible solutions to the removal of copper from ferrous scrap to avoid downgrading of automobile scrap. In addition, the USBM has investigated means to remove both copper and tin from ferrous scrap recovered from municipal solid waste.

Steel production generates a number of wastes that contain ferrous or nonferrous metal residues. The USBM has developed a process to recover nickel and chromium from acid solutions used to pickle (clean) stainless steel, and currently is investigating means to remove and recycle zinc and lead from BOF dust, allowing the remaining iron to be recovered from a waste material that is normally disposed on land. A process to produce high-quality graphite from kish, a common steel plant waste, was recently developed by the USBM and is being introduced at a major steel plant. In addition, investigations are underway of technology to separate and recover waste oils from steel plant sludge, allowing the contained iron to be recovered also.

Another area of investigation for the USBM has been the improvement of technology for remelting scrap. Studies of electric arc stability have led to the development of improved electric furnace practices that are quieter and more efficient.

Scrap Prices and Markets: Many industrial scrap producers sell their scrap by sealed bid auction on a monthly basis. The auction prices paid to several major companies—such as Ford, Chrysler, and Conrail—are widely known and published in *American Metal Market (AMM)*. *AMM* and *Iron Age Scrap Price Bulletin (IA)* survey brokers and consumers and publish estimated price ranges. Prices are quoted for a large number of different scrap grades and markets. Quoted prices differ significantly from city to city depending on market conditions. The *Wall Street Journal* publishes a price for a commonly traded scrap grade, No. 1 Heavy Melting Steel, Chicago market, daily.

Both *AMM* and *IA* compile a three-city (Chicago, Pittsburgh, Philadelphia) composite price for No. 1 Heavy Melting Steel. Historical series of monthly averages of these composite prices are often used to study trends. During 1991, the *AMM* three-city composite monthly average price ranged from a high of $105.04 (per long ton) in January to a low of $85.67 in December. The annual average for 1991 was $93.26.

European and world price evaluations are published weekly in *Metal Bulletin* (London). Reported prices for specific transactions in the Asian market are published in the *TEX Report* (Tokyo).

Scrap prices in the United States are quoted in dollars per long ton (2240 lb). In world trade, prices are quoted in dollars (or other currency) per metric ton.

Prices for individual scrap purchases and sales are based on negotiations. Contracts for periods longer than one month usually provide for monthly pricing and often are indexed to a published reference price.

Specifications for iron and steel scrap grades are published by the Institute of Scrap Recycling Industries, Inc. (ISRI) (Scrap Specifications Circular 1991). Specifications of individual buyers usually follow the nomenclature of the ISRI specifications, but may not be identical to them.

World Iron and Steel Recycling: The United States is the largest exporting nation of scrap iron and steel. Each year, about 10 Mmt of scrap are exported and about 1 Mmt are imported to the United States. Canada is the largest import source, with scrap moving freely in both directions in the border area. Similar trade exists between the United States and Mexico. In recent years, Turkey, Korea, and India have become the most important destination markets for U.S. scrap. Japan, which once was the most important destination for U.S. scrap, has become more self-sufficient and much less a factor in U.S. scrap trade, although the sheer size of the Japanese steel industry makes it an important potential market, particularly in times of high production. Other countries that are major exporters of scrap include the northern European nations of the United Kingdom, Germany, France, Belgium, and the Netherlands. Most scrap from these nations moves to southern

Europe—Italy and Spain. The European Community as a whole is neither a major source nor a major market for non-European scrap.

The United States imposes no duty on scrap imports from Canada, Mexico or other most favored nations.

Outlook: No problem is expected in finding a ready market to recycle obsolete iron and steel products into new products. Technological advances in steelmaking and processing have increased the range of steel products that are being produced by electric furnaces. As a result, demand for scrap in the United States is expected to increase as new electric furnaces are built. Plants that produce direct-reduced iron will be built to provide residual-free material that will dilute residuals in scrap. However, these plants are not likely to be built in the United States, because of the availability of lower cost iron ore and energy in other countries.

Figure 1.
Annual iron and steel recycling
(Million metric tons)

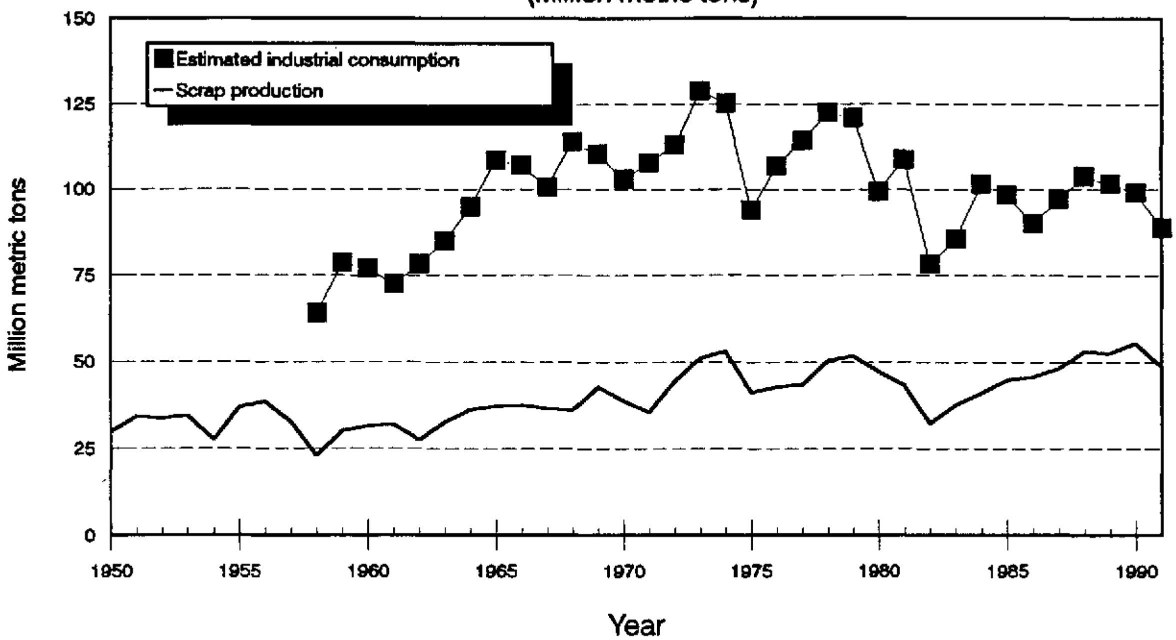
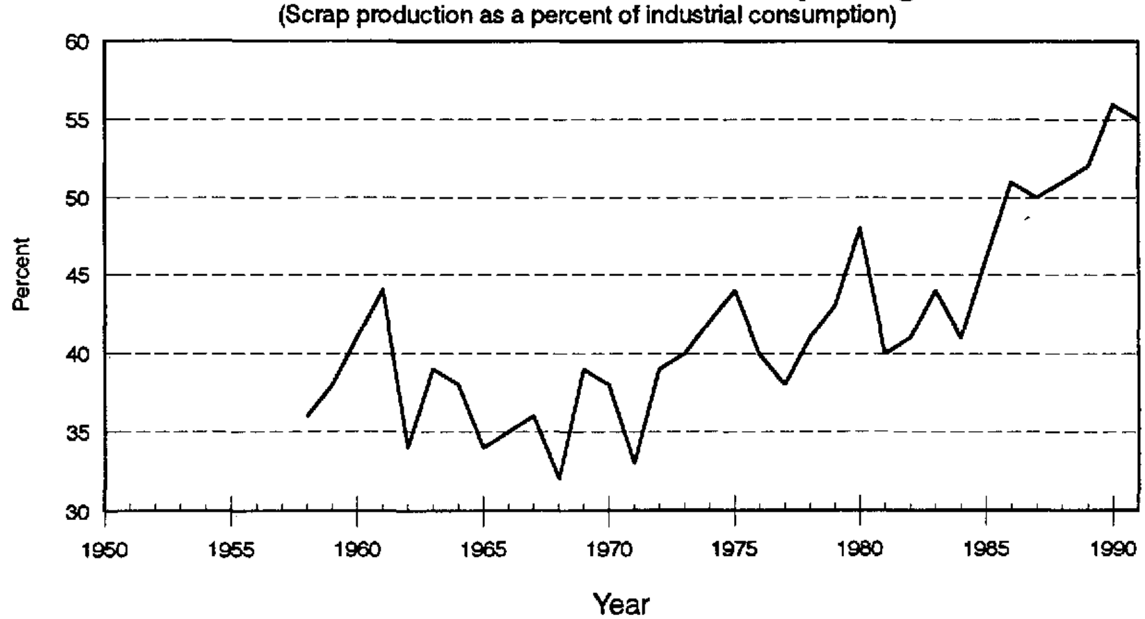


Figure 2.
Annual iron and steel recycling
(Scrap production as a percent of industrial consumption)



Pb

LEAD

by Daniel L. Edelstein

Salient Facts: Refined lead is a soft, heavy metal, which was one of the first metals used by man. It has a low melting point, which makes it among the easiest metals to cast, is the most corrosion resistant common metal, and has unusual electrical properties. In terms of tonnage of metal consumed, demand for lead is surpassed only by iron, aluminum, copper, and zinc. The United States is the world's largest producer and consumer of refined lead. The domestic demand pattern for lead has changed significantly over the past 20 years. In 1972 dissipative uses of lead, including gasoline additives, pigments, ammunition, and chemicals, amounted to over 400,000 mt, or about 30% of a reported consumption of 1.35 Mmt. In 1991, following the phase out of lead-base gasoline additives and pigments for interior paint, dissipative use accounted for less than 150,000 mt, or 11% of a total demand of 1.25 Mmt.

Salient Lead Statistics, United States
(Thousand metric tons)

	1950	1960	1970	1980	1990
Reported consumption	1,123	926	1,234	1,070	1,275
Lead recovered from scrap:					
New scrap:					
Lead-base	42	51	78	90	43
Copper-tin-base	8	5	4	4	5
Total[1]	50	56	83	94	48
Percent of consumption	5	6	5	5	4
Old scrap:					
Battery lead	220	232	318	481	786
Other lead-base	148	122	126	88	78
Copper-tin-base	20	17	15	13	11
Total[1]	388	370	459	581	875
Percent of consumption	34	40	37	54	69
Grand total[1]	438	426	542	676	922
Percent of consumption	39	46	42	59	73
Form of recovery:					
Soft lead	117	134	144	315	461
Antimonial lead	205	163	316	307	425
Other lead alloys	115	105	70	42	19
Copper-tin-base alloys	--	--	12	12	20
Total[1]	438	426	542	676	922
Imports of scrap, lead content	18	7	3	7	[2]
Exports of scrap, gross wt.	4	5	4	120	76

[1]Data may not add due to independent rounding.
[2]Less than one-half unit.

In 1991, lead was consumed at about 220 manufacturing plants. Transportation was the largest end use, with about 70% of demand consumed in batteries, fuel tanks, solder, seals, and bearings. Electrical, electronic and communications uses (including batteries), ammunition, TV glass, construction (including radiation shielding), and protective coatings accounted for at least another 25% of consumption, with miscellaneous uses such ballast, ceramics, crystal glass, type metal, etc., accounting for the balance. Lead-acid storage batteries, when extracted from all transportation and industrial uses, accounted for about 81% of 1991 demand. In 1991, 830,000 mt of lead were recovered from old scrap processed in the United States and accounted for about 67% of domestic reported demand for lead. In addition to old scrap, 54,000 mt of lead (6% of total secondary lead) was recovered from new scrap. Old scrap as a percentage of demand has trended upward in recent years. Old scrap accounted for about 40% of demand in the 1950-60 period. In 1991, U.S. imports of lead scrap were negligible, while the gross weight of exports was almost 130,000 mt.

At yearend 1991, the secondary lead industry consisted of 16 companies that operated 23 battery breakers-smelters with capacities of between 10,000 and 120,000 mt/yr; 5 smaller operations with capacities between 6,000 and 10,000 mt/yr; and 15 small plants (less than 1,000 mt/yr) that produced mainly specialty alloys for solders, brass and bronze ingots, and miscellaneous uses. Ten mines and three refineries, accounted for 95% and 100%, respectively, of domestic primary production.

In recent years, integrated battery manufacturers and secondary smelters have expanded smelting capacity to fill a vacuum left by the closure of small and medium sized, nonintegrated, battery breaking and/or secondary smelters that have succumbed to increasing environmental pressure. Similarly, the independent scrap dealer is playing a diminished role as battery manufacturers are entering into buy-back arrangements with retail outlets, both as a marketing tool for batteries and as a means of ensuring feedstock to their smelters and downstream manufacturing operations.

Sources of Secondary Lead: Secondary lead is recovered from old scrap (wornout, damaged, or obsolete manufactured products) and new scrap (purchased product wastes and smelter-refinery drosses, residues, and slags). The chief source of old scrap, hence of all lead scrap, in the United States and other industrialized countries is lead-acid storage batteries used in transportation and industrial applications. In 1991, over 90% of old scrap was derived from this source. Other sources of lead-base old scrap include cable coverings, pipe, sheet, terne or bearing metals, and solder. Much of the scrap cable sheathing and solder is recovered at secondary copper smelters, which manually strip lead sheathing from cables or sweat the solder from scrap radiators prior to copper smelting. Solder, a tin-base alloy, may also be recovered from the processing of circuit boards. Since most lead scrap is a mixture of alloys and lead compounds, most secondary lead recovered is collected, smelted, and refined at secondary plants to produce soft lead and antimonial lead or other lead-base alloys. A small amount is recovered from copper-base and tin-base scrap directly as alloys.

In recent years, lead recovered from old scrap has increased its dominance of the secondary market and its total share of domestic supply. Historically (1940-74) domestic primary and secondary lead (old scrap) production were about equal. However, beginning in 1974, with the phaseout of lead-base gasoline additives, which for technical reasons required the use of primary lead, secondary lead has increased its market share. In addition, legislation enacted by at least 37 States that requires mandatory take-back or bans landfill disposal of junked batteries has helped to push the recycle rate for spent automotive-type batteries to over 98%. With only a few nonsubstantive exceptions, primary and secondary lead have become equally competitive from the standpoint of price, quality, and specification.

A materials balance for the supply and demand for lead, including net trade, conducted for the 1940-88 period, suggests that about 20% (10 Mmt) of the lead consumed domestically over that period is still in use and is theoretically still available for recycling. However, the practicality of recovery is questionable given that some of the material remains abandoned (pipes and cable sheathing), some is contaminated from use in nuclear reactors or various containment vessels, and some, such as casket liners, has been removed from consideration.

Recovery Methods: While some secondary lead is recovered directly as babbitt metal, solder, remelt, and copper-base alloys, about 97% of secondary lead is recovered at secondary lead smelters and refineries as either soft (unalloyed) or antimonial lead. Unlike copper and zinc, where scrap processing varies tremendously by scrap type and ultimate use, the dominance of lead battery scrap allows for a more standard secondary recovery process. Prior to smelting, batteries must be broken by one of several techniques, and classified into its constituent products. The modern battery breaking process classifies the lead into metallic, oxide and sulfate fractions, and organics into separate casing and plate separator fractions. Cleaned polypropylene case fragments are recycled back into battery cases or other products. The dilute sulfuric acid is either neutralized for disposal, or recycled into the local acid market. Three main smelting processes are used to reduce the lead fractions to produce lead bullion. The majority of domestic battery scrap is processed in blast furnaces or rotary reverberatory furnaces. During smelting, battery scrap, along with iron, limestone, and coke, is fed into the furnace to produce a bullion, containing the lead values, an iron-sulfur matte, and a metal deficient slag. The reverberatory furnace is more suitable for processing fine particles and may be used in parallel to the blast furnace. Short (batch) or long (continuous) rotary furnaces may be used. Slags from the reverberatory furnace are processed through the blast furnace for recovery of alloying elements.

Newer plants may include lead paste desulfurization to reduce sulfur dioxide emissions and waste sludge generation during smelting. At the Doe Run Resource Recycling Facility, battery paste containing lead sulfate and lead oxide is desulfurized with soda ash to produce a market grade sodium sulfate solution. The desulfurized paste is processed in a reverberatory furnace. The lead carbonate product then may be treated in a short rotary furnace. The battery grids and posts are processed separately in a rotary melter. Though not yet employed in the United States, at least one domestic secondary lead producer was reported to be considering electrowinning of desulfurized lead oxides as an alternative to conventional smelting. Lead bullion is refined in a series of kettles to remove copper and minor impurities including antimony, arsenic, selenium, tellurium, nickel, tin, etc. The low- or non-antimonial calcium alloys currently used in batteries require an extremely high-purity lead.

Secondary Products: The principal products recovered from lead-base scrap are refined (soft) lead and antimonial lead, most of which is recycled directly back into the manufacture of new batteries. In 1991, soft lead and antimonial lead were produced in equal proportions and together accounted for 97% of secondary lead production. The balance was contained in lead-base alloys such as solder and copper- and tin-base alloys.

Scrap Prices and Sources: Prices for lead scrap are linked to the price of refined lead, the smelting cost or margin required to process the scrap, the type and quality of the scrap, specific contract arrangements, and local market conditions. Published U.S. and North American producer prices for refined lead are published in *American Metal Market* (*AMM*) and *Metals Week*. It should be noted that the published prices, as quoted by the producers, do not include discounts or reflect the actual transaction price, which may be tied to contract prices on the London Metals Exchange. Secondary smelter buying prices for various grades of scrap including remelt, cable lead, and whole batteries (about 50% lead content) delivered to the plant site are published in *AMM*. A scrap merchant buying price for whole, drained batteries is also published. While scrap prices generally track significant movements in the refined price, the margin, or spread between scrap and refined prices, may fluctuate owing to given market conditions for scrap. Higher lead prices generally allow for larger margins for secondary smelters. In the case of batteries, technical innovation has maintained processing costs at about 15 cents per pound of contained lead despite increased regulatory costs. In 1991, the estimated average margin between the purchased price of lead contained in battery scrap and the *Metals Week* producer price for refined lead was estimated at about 22 cents per pound.

Scrap batteries are increasingly recycled through buy-back arrangements between the distributor and the battery manufacturer, who will either process the batteries in its own secondary smelter or have them toll processed. Such arrangements reduce price transparency and may lead to tight supplies and higher prices for independent secondary smelters who may have to purchase a larger share of their scrap on the open market.

World Lead Recycling: Western World production of refined lead in 1991 was about 4.4 million tons. Western Europe was the largest consuming and producing region for refined lead followed by the United States and Japan. About 50% of Western World refined production was from secondary material. When compared on a regional basis, there were significant differences in secondary production as a percentage of total refined production: the United States, 71%; Europe, 50%; and Japan, 34%. Regional differences can be attributed to production and trade patterns for primary materials as well as consumption patterns for refined lead, more than to secondary lead collection efforts. In the United States, batteries, which are the prime source of secondary lead, account for about 80% of U.S. lead demand; in Europe, batteries on average account for only about 50% of demand. Conversely, chemicals and pigments, which do not lend themselves to secondary recovery, and piping and sheathing, which have a much greater service life, account for a greater share of European consumption.

Outlook: U.S. demand for lead is projected to grow at an annual rate of 0.5% to 1.5%. This rate is significantly lower than the 4% annual growth of the 1985-89 period. Environmental legislation and source reduction activities are expected to continue the downward trend in dissipative uses of lead, such as paint and ammunition, as well as nondissipative uses such as solder and glass, for which there is limited secondary recovery. Even though some reduction in lead per battery unit is expected, lead-acid storage batteries are expected to increasingly dominate demand. This will be particularly true if load leveling applications are more widely accepted and demand for private, general purpose electric cars materializes. While numerous storage battery materials are under consideration for use in electric vehicles, it is likely that at least near term production of electric vehicles will rely on lead-acid batteries. Based on prototypes under consideration, each electric vehicle could require 750 lb of battery lead. The increased dominance of lead-acid storage batteries, the already high recycle rates for batteries, and increasing regulatory pressure to keep lead out of the municipal waste stream, will all serve to boost collection and production of secondary lead. Assuming an overall annual growth rate in lead consumption of 1.5% through the year 2000, all attributable to batteries, secondary lead, as a percentage of apparent consumption, could continue to rise from its current level of 73% by about 5%. Demand growth, remaining dissipative uses, and processing losses would pose an upward limit on scrap market share.

Mg

MAGNESIUM

by Deborah A. Kramer

Salient Facts: Magnesium metal is used primarily as an alloying component in aluminum alloys, averaging about 50% of consumption annually. These aluminum alloys are used in a variety of applications including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys. Magnesium and its alloys also are used as structural components in automobiles, trucks, aircraft, computers, and power tools. Smaller-volume uses for magnesium include external hot-metal desulfurization of iron and steel, production of some nonferrous metals, sacrificial anodes for protection of underground pipe and water tanks, and as a catalyst for producing organic compounds. In 1991, almost 40% of the U.S. apparent consumption for magnesium metal was supplied by secondary magnesium recovered from magnesium- and aluminum-base scrap. Old (post-consumer) scrap represented 22% of domestic magnesium demand.

Salient Magnesium Statistics, United States
(Thousand metric tons)

	1960	1970	1980	1990	1991
Primary production	36	102	[1]154	139	131
Secondary production (new and old scrap)	9	11	37	55	51
Apparent consumption	48	88	117	145	134
Secondary production as a percent of apparent consumption	19	13	32	38	38
Net import reliance as a percent of apparent consumption	17	E	E	E	E
U.S. scrap trade[2]					
Imports	NA	NA	2	4	4
Exports	NA	NA	([3])	1	1

E Net exporter.
NA Not available.
[1]Derived from production reported by the International Magnesium Association and the Canadian Department of Energy, Mines and Resources.
[2]Source: U.S. Bureau of the Census.
[3]Less than 1/2 unit.

Sources of Secondary Magnesium: Recycled magnesium is derived from two sources: aluminum- and magnesium-base scrap. Aluminum-base scrap consists of both new and old scrap of aluminum-magnesium alloys. The primary component of aluminum-base scrap, from which magnesium is recovered, is aluminum beverage cans. Although only about 75% of the magnesium originally present in these types of alloys is recovered, it represents a substantial source of secondary magnesium. Magnesium in these aluminum alloys is not separated from the aluminum, rather it remains as an alloying constituent when the beverage can scrap is recycled. Because much of the magnesium is recycled along with the aluminum, not as much primary magnesium is needed to produce the aluminum alloys as if they were produced from virgin material.

Magnesium-base scrap generally is in forms similar to those of other nonferrous metals. Castings, gates, runners, drippings, turnings, and drosses from processing operations are the principal sources of new scrap. Old scrap comes from a variety of sources, including aircraft parts, such as wheels, fuselages, and control panels; military applications, such as incendiary bombs and tent support poles; and discarded power tools, such as lawnmower decks, chainsaws, and hand tools. The diecasting industry is the largest source of old magnesium-base scrap. Historically, the largest single source of old magnesium-base scrap was the Volkswagen Beetle, which was the largest structural use of magnesium. In the mid-1970's, Volkswagen production consumed about 45,000 mt of magnesium annually—about 18 kg per vehicle.

The total magnesium recovered from scrap, shown in the following table, increased significantly between 1970 and 1980. This primarily resulted from the wide acceptance of aluminum beverage cans, resulting in the large-scale recycling of used beverage cans, and the new scrap generated during the can manufacturing process.

Magnesium recovered from scrap processed in the United States, by kind of scrap and form of recovery
(Metric tons)

	1951	1960	1970	1980	1990	1991
KIND OF SCRAP						
New scrap:						
Magnesium-base	3,381	2,884	4,140	5,379	3,992	4,867
Aluminum-base	1,487	2,563	4,262	15,402	19,432	18,192
Total	4,868	5,447	8,402	20,781	23,423	23,059
Old scrap:						
Magnesium-base	4,868	3,230	1,377	4,785	4,277	4,443
Aluminum-base	720	711	1,145	11,140	27,107	23,041
Total	5,588	3,941	2,522	15,925	31,383	27,484
Grand total	10,456	9,388	10,924	36,706	54,806	50,543
FORM OF RECOVERY						
Magnesium alloy ingot[1]	5,136	3,473	1,820	3,815	4,290	4,604
Magnesium alloy castings	1,519	94	12	758	857	1,043
Magnesium alloy shapes	23	3	171	2,852	301	158
Aluminum alloys	3,078	2,910	6,430	26,864	46,807	41,606
Zinc and other alloys	50	49	22	12	W	3
Chemical and other dissipative uses	92	231	72	8	W	W
Cathodic protection	558	2,628	2,397	2,397	W	W
Total	10,456	9,388	10,924	36,706	54,806	50,543

W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."
[1]Includes secondary magnesium content of both secondary and primary alloy ingot.

Recovery Methods: Melting is the most common process used to recycle magnesium, because it allows almost all types of scrap to be processed into various secondary end products. Magnesium scrap normally is received loose on trailers. Because magnesium resembles aluminum closely, there is usually a certain percentage of aluminum scrap mixed in the with magnesium scrap. The aluminum scrap is hand sorted from the magnesium scrap, and the magnesium scrap then is sorted by alloy. Sorting is a critical step in producing a product of desired specifications.

In melting, sorted scrap is charged to a steel crucible, 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.

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 process.

Scrap Prices: Because of recent introduction of high-purity magnesium alloys, with stringent purity specifications, diecasters no longer find it practical to recycle their magnesium scrap in-house and maintain these specifications. In most cases the die-cast scrap is handled by secondary facilities on a tolling or purchase basis. Because of the limited quantity of magnesium scrap that is sold (compared to most other nonferrous metals), prices for magnesium scrap are negotiated between supplier and customer. As with other metals, the quality of the product is significant in determining the price of the scrap. Overall magnesium supply and demand also are important in determining scrap prices.

Outlook: The recent development of high-purity magnesium-base alloys was instrumental in increasing automotive applications of magnesium. Magnesium constitutes about 4% of the total weight of the average U.S. passenger car. This level is projected to grow rapidly as automobile manufacturers specify more magnesium components for vehicles built during the remainder of the 1990's. (Magnesium, because of its light weight, is an important factor in helping U.S. auto manufacturers meet higher Corporate Average Fuel Economy standards.)

As automobile manufacturers begin to use more magnesium components, the supply of old magnesium scrap is likely to increase significantly, supplying a greater share of U.S. demand. The average life of an automobile is estimated to be about 11 years, so there will be a significant time lag between the increase of magnesium parts in automobiles and any increase in secondary magnesium from this source.

At the same time, used beverage cans will continue to be an important source of secondary magnesium. Several factors will work both for and against an increase in secondary magnesium available from aluminum cans. As population continues to grow, there will be a greater demand for aluminum beverage cans, and increases in can recycling rates (one of the most often recycled products) will increase the supply of secondary magnesium. At the same time, can manufacturers are using less magnesium per can, so that would tend to decrease the total secondary magnesium available from this source. Most likely, the secondary magnesium supply from aluminum-base scrap will grow slowly over the next few years.

Mn

MANGANESE

by Thomas S. Jones

Salient Facts: Manganese is essential to the production of steel, which on average contains about 0.7% manganese. Manganese is ubiquitous throughout the various grades of steel, so that the main usage pattern for manganese roughly parallels that for steel. Leading consuming sectors for manganese are construction, transportation, and machinery. Steelmaking and other metallurgical uses account for 90% or more of domestic demand for manganese. The balance of manganese demand consists of nonmetallurgical applications such as in dry cell batteries (around 5% of demand), brick coloring, animal feed, and plant fertilizer. U.S. apparent consumption of manganese was, in thousand metric tons as follows: 1950, 1,060; 1960, 977; 1970, 1,204; 1980, 933; and 1990, 630. The falloff between 1980 and 1990 reflected technological changes in steelmaking that significantly lowered the amount of manganese used per ton of steel produced.

Recovery Methods: Considerable manganese is recycled as a constituent of iron and steel scrap being recovered primarily for its iron units. Recycling of iron and steel scrap is discussed in the respective chapter of this report. The manganese units in purchased scrap consumed in steelmaking are roughly one-third as great as the manganese units in the steel produced. Manganese is oxidized during steelmaking, so that steel scrap recycling does not cause a progressive buildup in steel manganese content. Scrap recovery specifically for manganese is insignificant. Production of high-manganese (Hadfield) steel having a manganese content of about 12% is quite small relative to total steel production. The quantity of this type of steel recovered for its manganese content is believed to be well below 1% of the total quantity of purchased steel scrap.

A majority of the manganese units employed in steelmaking end up in steel slag, chief uses of which are construction and road building. A diminishing proportion of steel slag is recycled to the ironmaking that precedes steelmaking, primarily also to reclaim iron and to reuse the lime and magnesia contents of the slag in forming new slag. The USBM and others have made various attempts over the years to develop techniques for recovering manganese from steel slag. The low manganese contents of such slag and the costs of processing it have, so far, made it uneconomical to put the procedures worked out into practice.

Manganese is recycled in the aluminum industry as a component of scrap of certain manganese-bearing aluminum alloys. A prime example is used beverage cans in which the manganese content is about 1%. Recycling of manganese in aluminum has an accumulative effect. Melting and processing of aluminum is nonoxidizing toward manganese, so that most of the manganese is retained. Thus, the increasing emphasis on aluminum recycling suppresses primary manganese demand by the aluminum industry. Use of manganese as an alloying element for aluminum represents only a few percent of total domestic demand for manganese.

Outlook: For manganese, the pattern of recycling and quantities recycled are expected to remain substantially the same for the foreseeable future. The amount recycled will fluctuate principally in response to the level of activity in the steel industry. As a possibility for the longer term, a relatively small additional amount of manganese could be recovered through widespread recycling of dry cell batteries.

Hg

MERCURY

by Stephen M. Jasinski

Salient Facts: Domestic consumption of mercury has been decreasing for several years because of environmental problems associated with its use. In 1991, 33% of domestic consumption was in the manufacture of chlorine and caustic soda, the largest single use. Other significant uses were for measuring and control instruments, switches, and dental amalgams. Industrial secondary production was 165 mt. An additional 215 mt of secondary mercury was released from U.S. Department of Energy stocks.

Salient Mercury Statistics, United States
(Metric tons, mercury content)

	1950	1960	1970	1980	1990
Industrial demand (consumption)	1,697	1,764	2,120	2,033	720
Secondary production (industrial)	69	184	253	234	108
Secondary production as a percent of consumption	4	10	12	12	15

Sources of Secondary Mercury: Mercury is recovered from discarded electronic devices such as rectifiers, switches, thermostats, and relays. Scrap mercury also is collected from dental amalgams, batteries, and broken thermometers. The manufacture of chlorine and caustic soda accounts for most of the mercury waste generated in the United States. Mercury is contained in waste water and sludges, of which, about 60% are recycled internally. Mercury waste generated in the manufacturing of products (new scrap) is reused internally or collected for reprocessing. In 1991, 32% of domestic consumption was from secondary mercury.

In 1990, nearly 1,300 mt of mercury was estimated to have been lost to the environment from all sources. This figure includes estimates for losses from mining, fossil fuel combustion, refining, and manufacturing and from discarded products that contained mercury. Six hundred metric tons was estimated to have been lost from the disposal of batteries, very little of which was recycled. Of the additional 200 mt lost from scrap products, 108 was recovered.

Recovery Methods: Three companies, one each in Illinois, New York, and Pennsylvania, produced the bulk of secondary mercury in 1991. Mercury is usually recovered by retorting waste materials. A retort consists of an enclosed steel container that contains the wastes. The container is then heated to vaporize the mercury, which is collected by condensation. The mercury must then be distilled to remove base metals and other impurities. Higher purity mercury is often triple distilled. These are fairly simple and efficient processes, but precautions must be taken to prevent the escape of mercury vapor.

Outlook: The current trend in the United States is to substitute for mercury wherever possible. The disposal and incineration of mercury-containing wastes has been banned by several States. Recycling programs have been established in the past 2 years for used fluorescent lights and other products. The disposal of certain high-mercury content waste water and sludges generated in the manufacture of chlorine and caustic soda were banned by the EPA in 1992. The reprocessing of these wastes will increase U.S. secondary production by at least 25 mt per year.

Because of environmental concerns, the recovery of mercury from scrap materials will increase over the next 5 years. However, mercury consumption also will continue its downward trend in many applications such as:

- Mercury cell chlor-alkali plants — will gradually be phased out.
- Batteries — mercury will be eliminated from alkaline batteries by 1995 and the content of other batteries will be reduced.
- Lighting — less mercury will be used in fluorescent light tubes.
- Dentistry — replacement with composite ceramic materials.

Secondary mercury will contribute to a greater percentage of domestic supply in the future.

Mo

MOLYBDENUM

by John W. Blossom

Salient Facts: Molybdenum is a metallic refractory element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has ensured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal in numerous chemicals applications, including catalysts, lubricants, and pigments.

Sources of Secondary Molybdenum: The estimated total U.S. domestic consumption for 1991 was 26,000 mt of molybdenum. An estimated 8,000 mt of molybdenum was consumed in products that could not be recycled and therefore was dissipated in the environment. It is estimated that 2,400 mt was recovered from recycling spent catalysts. Metal scrap containing 544 mt of molybdenum was reported consumed in the production of superalloys. The amount of molybdenum contained in the steel alloy scrap and pure molybdenum metal scrap is not reported. It is known that, in the manufacturing of new steel alloys, the melt is checked for the percentage of contained molybdenum, and additional molybdenum is added if needed to obtain the correct percentage of molybdenum. The molybdenum scrap, generated in the production of molybdenum metal products (powder, bars, sheet, fail, tubing, etc.) and fabrication of molybdenum items, is collected and sold to alloy producers. The quantity and quality of this scrap is not reported.

Recovery Methods: Spent catalysts are recycled with hydrometallurgical processes. Metal scrap (old scrap) is collected and sold to alloy producers.

Outlook: Prospects for increasing the present level of recycling molybdenum is associated with EPA requirements and not on the demand for for molybdenum as it is less costly to mine molybdenum than to recycle it.

Ni

NICKEL

by Peter H. Kuck

Salient Facts: Nickel is critical in today's highly industrialized and technological society because of its myriad of applications. The element has both unique alloying and catalytic properties. Many alloys containing nickel are highly resistant to corrosion and oxidation. A number of these alloys also exhibit excellent strength and toughness at elevated temperatures. More than half of the nickel consumed in the world in 1992 went to make austenitic stainless steel. Significant amounts of nickel were also used in alloy steels, superalloys, magnetic alloys, copper-base alloys, aluminum-base alloys, and electroplating.

More than one-fourth of the 145,000 mt of nickel consumed annually by the United States is of secondary origin (fig. 1). Domestic industries recycled at least 40,300 mt of nickel in 1991, saving the country an estimated $325 million in foreign exchange. About 73% (29,400 mt) came from stainless steel scrap and alloy steel scrap. The United States is not only a major consumer of stainless scrap, but also a net exporter of the material. In 1991, exports of stainless scrap contained about 17,400 mt of nickel and were valued at $196 million. An additional 10,400 mt of nickel left the country either as nickel-base alloy scrap or in a variety of upgraded processing residues.

The country's only primary nickel producer—a ferronickel operation in Oregon—recovered 5,523 mt of the metal as ferronickel from local laterites in 1991. The Oregon operation, however, was able to supply only about 4% of the Nation's needs. To meet the remaining 96% of demand, 132,000 mt of primary nickel was imported at a cost of $1.12 billion. More than half came directly or indirectly from Canada as 99.5% plus pure metal, mostly in the form of cut cathode or powder. An additional 6,200 mt of impure nickel was brought into the country for recycling. The 6,200 mt included $23 million of stainless scrap containing 2,500 mt of nickel and $35 million of nickel-base alloy scrap and processing residues containing an estimated 3,700 mt of nickel.

Secondary Sources of Nickel and Recovery Methods: Between 75% and 85% of the nickel recycled in the United States starts out and ends up as stainless steel (fig. 2). New stainless scrap is generated at a variety of manufacturing and fabricating facilities. This new material may include clippings, trimmings, turnings, or grindings.

Stainless reaction vessels, heat exchangers, ducts, pipes, and valves are salvaged when obsolete chemical plants and petroleum refineries are dismantled. Discarded commercial and household kitchen fixtures, food processing equipment, and cooking vessels are collected at hundreds of domestic scrap yards. Old scrap also comes from more than 200 automobile and appliance shredding centers.

Stainless scrap typically contains 6% to 11% nickel. At the steel plants, processed scrap is melted in electric furnaces. Primary nickel cathode, ferronickel, or metallurgical-grade nickel oxide is added to bring the nickel content up to specification.

Since 1978, a Pennsylvania plant has been converting a wide range of nickel and chromium wastes into nickel-bearing remelt alloys suitable for stainless steelmaking. Mill scale, swarf, and flue dust from stainless steel plants make up the bulk of the feed for the pyrometallurgical process. The plant also accepts plating cakes, plating solutions, spent catalysts, various baghouse dusts, and used nickel-cadmium batteries.

Nonferrous scrap is the next largest source of secondary nickel, accounting for roughly 10% to 12% of the total tonnage recycled each year. Nickel can be recovered during the recycling of a variety of aluminum-base, copper-base, and zinc-base alloys. Copper alloy scrap is increasingly being accepted by primary copper smelters and refineries as part of their normal feed. The alloyed nickel is recovered in a matte separate or in an electrolytic slime together with primary nickel concentrated from the copper ores. Byproduct crude nickel sulfate is produced by at least four primary copper refineries and two secondary copper refineries.

Only part of the nickel coming out of copper refineries is derived from scrap. Some nickel occurs in the copper ores as primary sulfides or arsenides and accompanies the copper through the bulk flotation circuit. Separation can be difficult sometimes because minor amounts of pentlandite ($[Ni,Fe]_9S_8$) are frequently intergrown with the chalcopyrite or bornite. Nickel can also substitute for iron to a limited extent in associated iron sulfides, such as pyrrhotite and pyrite.

Superalloy scrap is a third important source of secondary nickel. Although the material represents less than 10% of the total nickel being recycled, it frequently contains between 40% and 80% nickel and has a high unit dollar value in terms of gross weight. Cobalt credits can add dramatically to the unit value in some cases. Superalloy scrap is generated during the fabrication of aircraft engines and chemical processing equipment.

Some material (e.g., turbine blades) is also salvaged from obsolete aircraft or collected at maintenance shops that service and repair turbine engines. Because of the stringent specifications for superalloys, only a small amount of the scrap generated can be recycled into superalloys. As a result, much of this scrap is sold to secondary metal refiners for use in stainless steel. If all of the superalloy material processed in 1986 had been mixed together, the composite alloy would have contained about 44% nickel, 16% chromium, 5% cobalt, and 5% niobium.

The USBM has been exploring ways of recycling superalloy scrap for more than a decade. Because of the high nickel and/or cobalt content of much of this scrap, sophisticated pyrometallurgical or electrowinning processes may be economically justifiable when demand and prices are high. The USBM Rolla Research Center recently developed an electrorefining process that recovers 90% of the nickel and cobalt in mixed and contaminated superalloy scrap. The process uses controlled-potential electrolysis to selectively deposit a nickel-cobalt alloy.

The Albany Research Center has shown that the individual metals in mixed superalloy scrap can be recovered using a combination of pyrometallurgical and hydrometallurgical methods. The mixed scrap is first melted and converted to a matte by adding sulfur to the melt. Next, the molten matte is granulated, allowed to cool, and ground. The ground matte can be leached by bubbling chlorine gas through an aqueous solution of hydrochloric acid. The nickel, cobalt, chromium, iron, and molybdenum in the leach solution can then be separated from one another by selective solvent extraction, precipitation, or electrowinning.

In the early 1980's, USBM researchers developed a portable unit for identifying, sorting, and upgrading superalloy scrap stored at military depots. The operator was able to distinguish between different types of superalloys on the basis of their characteristic spark spectra. Today, scrap dealers can purchase portable, computerized optical and x-ray emission spectrometers from commercial vendors that make sorting even easier and more exact.

Scrap Prices and Price Sources: Domestic prices for different types of stainless steel scrap are published daily in *American Metal Market* and similar trade publications. These prices may vary slightly from city to city. During 1992, the consumer buying price for 18/8 stainless scrap bundles in Pittsburgh ranged from $625 to $870 per short ton gross weight. These values equate to $689 to $959 per metric ton gross weight. Prices for nickel-base scrap are normally negotiated on the basis of the daily London Metal Exchange (LME) price for nickel cathode.

Outlook: For the near term (1993-95) and midterm (1996-98), recycling is not expected to exceed 40% of total apparent consumption. Recent environmental legislation may increase secondary recovery to a limited extent over the 5-year period. But, at the same time, the current low price of virgin nickel, ample supplies of Russian cathode in LME warehouses, and the long life of stainless steel will discourage any sharp increase in traditional recycling.

Forecasting long term U.S. demand for nickel is difficult because of the technical uncertainties associated with future production of electric vehicles. If the nickel-metal hydride (NiMH) storage battery proves to be the power source of choice, demand for nickel by U.S. battery manufacturers could approach or even exceed the tonnage used in stainless steel by the year 2005. A single NiMH battery pack could conceivably require as much as 125 kg of nickel. Several Japanese and European automobile manufacturers have developed advanced nickel-cadmium battery prototypes that look promising. The sodium metal-nickel dichloride battery may also be technically feasible. However, all three nickel batteries could be dropped in favor of competing battery systems, such as sodium-sulfur, zinc-air, advanced lead, or lithium-polymer.

Present-day nickel recycling would change dramatically if any one of the nickel-base storage batteries wins out. The relatively high dollar value of the nickel inside the spent battery pack, plus the sheer weight and compactness of the pack, should lead to almost 100% recovery of battery production.

Figure 1.
Annual nickel recycling
(Thousand metric tons, nickel content)

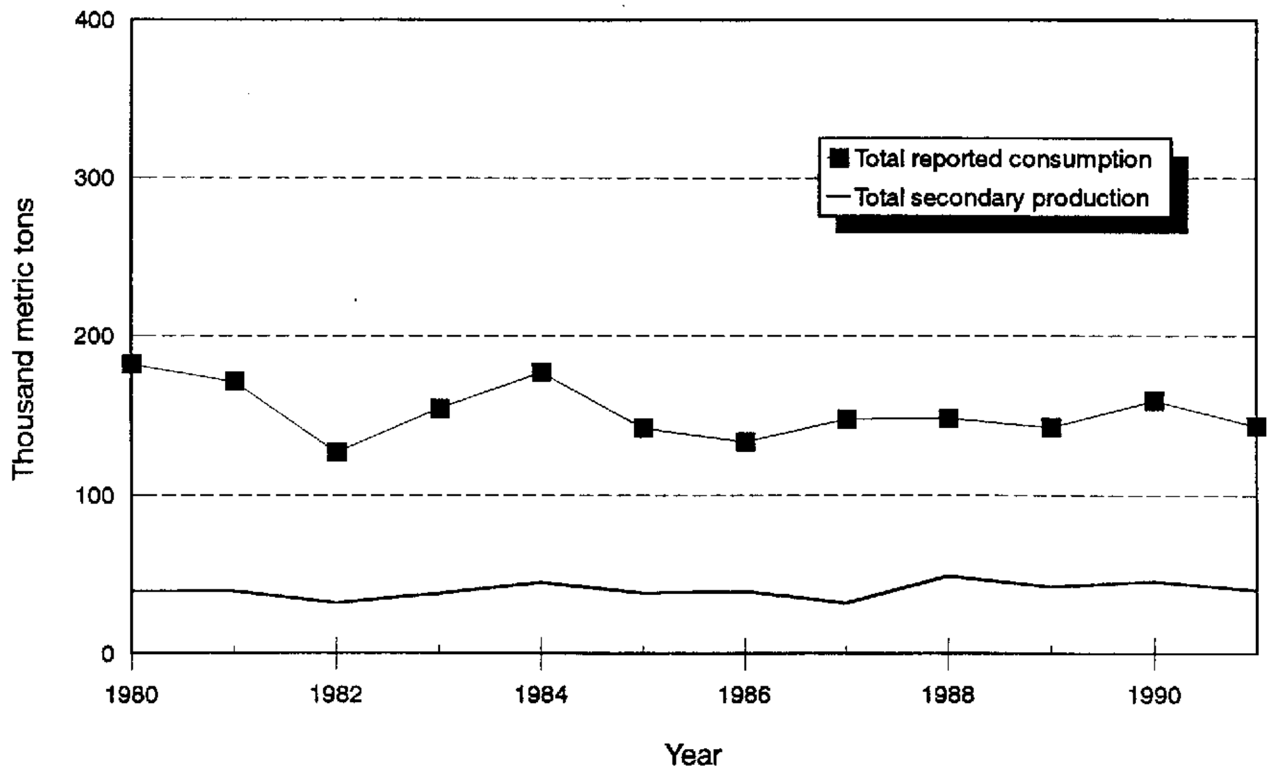
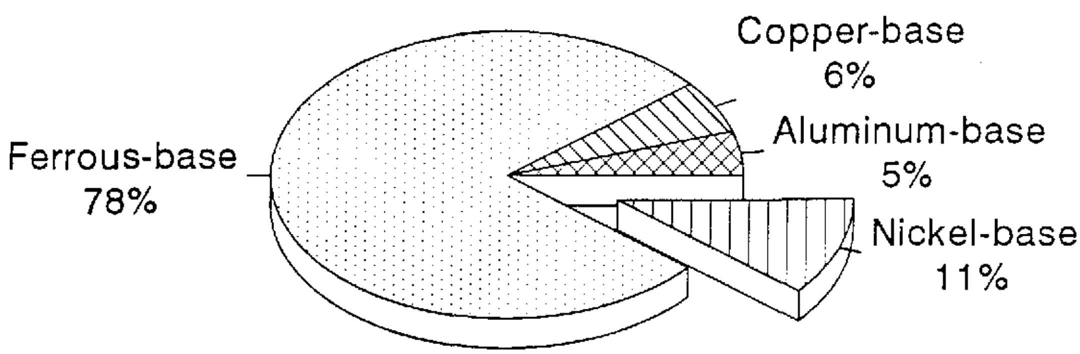


Figure 2.
Nickel recovered from purchased scrap in 1991



40,300 METRIC TONS OF CONTAINED NICKEL

Pt, Pd, Ir, Os, Rh, Ru
PLATINUM-GROUP METALS

by J. Roger Loebenstein

Salient Facts: Platinum-group metals (PGM), along with gold and silver, are precious metals. Of the PGM, platinum, palladium, and rhodium have the most important industrial applications. The leading industrial use for platinum is for automotive emissions control (60%); the leading industrial use for palladium is for electronic uses (50%); and the leading industrial use for rhodium is for automotive emissions control (70%).

Because of their high value, PGM are routinely recovered from petroleum catalysts, chemical catalysts, automobile catalysts, glass fiber bushings, electronic scrap, laboratory equipment, dental materials, and jewelry. Refiners often charge a fee or toll to toll refine scrap; ownership of the PGM content of the scrap remains with the customer. If a customer chooses to sell scrap and not retain ownership of the metal, it is referred to as nontoll scrap. For statistical purposes, nontoll-refined scrap is considered as old scrap and is added to supply, along with newly mined metal; toll-refined scrap is not added to supply.

Gathering a representative sample of scrap and assaying the metal content of scrap are extremely important steps for both the owner of the scrap and the refiner. Because of its strategic applications and limited number of import sources, it is in the national interests to facilitate and encourage the maximum recovery of PGM from scrap. A PGM consumption and recycling flow model is described in the USBM Information Circular (IC) 9303, published in 1991.

Salient PGM Statistics, United States
(Kilograms)

	1950	1960	1970	1980	1990
Estimated industrial consumption	15,426	24,112	41,403	68,612	117,043
Secondary:					
Nontoll-refined	1,808	2,391	10,892	10,292	5,819
Toll-refined	NA	23,700	45,148	33,561	65,429
Total	NA	26,091	56,040	43,853	71,248
Nontoll-refined secondary production as a percent of consumption	12	10	26	15	5
U.S. scrap trade:					
Imports	276	96	1,997	11,710	4,614
Exports	NA	NA	2,349	5,296	34,487

NA Not available.

Sources of Scrap: In the United States, used catalytic converters, or automobile catalysts, are collected by numerous muffler shops and salvage dealers. These small collectors sell to large collectors who separate the outer stainless steel shells of the converters from their contents. The contents, or catalyst substrates, are shipped to precious metal companies who extract the platinum, palladium, and rhodium. Scrapped automobile catalysts contain about 30 troy ounces of PGM per short ton of catalyst, or about one kilogram of PGM per metric ton of catalyst. It was estimated that North American recovery of platinum from scrapped catalysts in 1990 was 5,443 kg, and for palladium was 1,866 kg. The amount of rhodium recovered in North America was undoubtedly much smaller but data are not available.

The largest collectors of automotive scrap are in Alabama, New Jersey, Tennessee, and Texas. The only domestic company that refines substantial amounts of PGM from scrapped catalysts is in Alabama. This company uses a plasma arc furnace to smelt the catalyst and produces a PGM concentrate that requires further refining.

Another commonly recycled catalyst is a 90% platinum, 10% rhodium woven wire catalyst used to produce nitric acid. Through use, the catalyst wears out and is generally returned to a PGM refiner for reprocessing.

In addition to chemical catalysts, petroleum catalysts containing platinum and/or rhenium are used in reforming catalysts for the production of gasoline. Reforming catalysts contain about 0.3% by weight of platinum. Most reforming catalysts are used about 4 or 5 years before they are recycled. Through use, the catalyst becomes ineffective from carbon and sulfur contamination. Petroleum catalysts are refined by two companies in California and one in Louisiana.

Electronic scrap contains approximately 47 grams of palladium per metric ton.[1] Very little of the other PGM are contained in electronic scrap. There are four steps involved in processing electronic scrap: hand sorting, calcination-combustion, shredding, and sampling. The telephone industry is a major collector and processor of electronic scrap from used telephone equipment. The U.S. Department of Defense collects obsolete electronic scrap from the military and contracts for the material to be refined. Mainframe computers are another source of electronic scrap.

Some scrap PGM is collected by dental and scientific laboratories, glass fiber manufacturers, and jewelry manufacturers.

Recovery Processes: Most PGM scrap can be concentrated by smelting, and then refined by electrolytic or chemical methods, such as acid leaching followed by solvent extraction or ion exchange. At its Reno Research Center, the USBM investigated using sodium cyanide solution to leach PGM from automobile catalysts.[2] Electronic scrap is generally hand sorted, incinerated to remove organics, and chemically treated.

The recycle processing losses are estimated at 3% for the petroleum catalyst industry, 10% for the automobile catalyst industry, and 15% for the chemical catalyst industry.

Outlook: The long term prospect for larger amounts of PGM to be recovered from automotive catalysts is good, given the need to control exhaust emissions. The Clean Air Act of 1990 requires a reduction in hydrocarbons and nitrogen oxides beginning in 1994. This will cause an increase the amount of PGM used in each catalytic converter. As the U.S. automobile industry recovers from record low sales in 1991, more cars will be sold, more scrapped automobile catalysts will be collected, and more PGM will refined. The secondary production of PGM as a percent of consumption should grow slowly because of the greater amounts of PGM being used in automobile catalysts.

[1]Hoffman, J. Recovering Precious Metals From Electronic Scrap. J. Met. July 1992, pp. 43-48.
[2]Kuczynski, R. J., G. B. Atkinson, and L. A. Walters. High-Temperature Cyanide Leaching of Platinum-Group Metals From Automobile Catalysts-Process Development Unit. BuMines RI 9428, 1992, 11 pp.

Se

SELENIUM

by Daniel L. Edelstein

Selenium, named after the Greek goddess of the moon Selene, is recovered as a byproduct of primary copper production. Its occurrence in nature is insufficient for its economic recovery as a principal product. In the United States, three refineries recover primary selenium from the anode slimes generated in the electrolytic refining of copper. Demand for selenium can be broadly divided into four categories: electronics, including photoconductor uses (35%); glass manufacturing (30%); pigments and chemicals (20%); and other; including agriculture and metallurgy (15%). Estimated apparent demand in 1991 was about 520 mt. Most domestic selenium is produced as commercial-grade material averaging a minimum of 99.5% selenium. The largest end use for domestic material is in glass manufacturing. Higher purity selenium used in electronic applications is imported.

With the exception of electronics applications, most uses of selenium are dissipative or end up as minor constituents of products that are landfilled. The small quantities added to clear glass as a decolorant or to ferrous and nonferrous metal alloys are not accounted for during the recycling of these materials, but are probably volatilized during melting. Selenium-tinted solar plate glass for the construction industry has a long useful life and is generally not subject to recycling.

Historically, the only secondary production of selenium has come from electronic applications. Domestic secondary production peaked in 1956 at an estimated 85 mt. While there is currently no domestic secondary selenium recovery, manufacturing scrap generated in the production of selenium-coated photoreceptor drums for plain paper copiers and wornout or obsolete photoreceptor drums (old scrap) is exported for recovery of the contained selenium. It is estimated that as much as 100 mt of selenium metal refined from scrap is imported annually. Secondary selenium is recovered by Canadian, European, Japanese, and Philippine refiners. Selenium rectifiers, which have to a large extent been replaced by silicon rectifiers, were once a source of secondary selenium. Currently, the costs associated with recycling existing stocks of used selenium rectifiers make reprocessing uneconomical. The outlook for selenium demand, based on existing applications is not encouraging. The photocopier market for selenium, currently the feed source for secondary selenium, is expected to decline or, at best, remain stable owing to competition from other technologies including organic photoreceptors and laser printing. This, combined with low prices, a movement toward refining even primary selenium offshore, and surplus foreign secondary capacity, is likely to discourage development of domestic secondary refining capacity.

Ag

SILVER

by Robert G. Reese, Jr.

Salient Facts: Silver has a large number of industrial applications. More than 50% of the silver consumed domestically is used in the manufacture of photographic products such as film and lithographic papers. Electrical and electronic products account for an additional 25% of the total domestic industrial demand. Important applications for silver in these products include contacts, plated parts, conductive paints and pastes, brazing alloys and solders, and wire. Other consumer goods manufactured using silver include jewelry, sterlingware, mirrors, and commemorative objects such as coins and medallions.

Prior to 1965, the most important domestic use for silver was in the manufacture of circulating U.S. coinage. From 1837 through 1964, U.S. coins, including dollars, half dollars, quarters, and dimes, consisted of a 90% silver and 10% copper alloy. Since 1965, nearly all the circulating coinage minted by the Federal Government have contained only base metals and little to no silver.

The belief that silver represents a store of value and wealth was the basis for its use as the standard for various monetary systems. This belief is a major factor in the flow of silver from manufacturer to consumer to recycler. Because of its perceived "value," great care is taken to avoid losing any of the metal. Every stage in the manufacturing process recycles silver. Because of this concept of "value," even the ultimate consumer of a product such as the purchaser of a piece of jewelry can be an important source of scrap silver. Silver-bearing scrap is purchased by hundreds of scrap yards and refiners. Shredding and/or melting of the scrap often occurs before shipping to a refiner. This action serves two purposes: it provides a homogenous mass for sampling to determine the value of the scrap, and it reduces the volume of material handled.

Salient Silver Statistics, United States
(Metric tons)

	1950	1960	1970	1980	1990	1991
Apparent demand:						
Refinery production						
Ores & concentrates	NA	NA	2,531	1,224	1,598	1,879
Old scrap	NA	NA	1,743	1,653	454	229
Total	1,316	1,145	4,274	2,877	2,052	2,108
Net imports (exports)						
of refined bullion	2,163	(281)	384	238	1,962	1,738
Total	3,479	863	4,658	3,115	4,014	3,846
Recycled:						
By industry						
Old scrap	NA	NA	1,743	1,653	454	229
New scrap	NA	NA	746	2,042	1,221	1,634
Total	[1]1,408	[1]1,524	2,489	3,695	1,675	1,863
By Government	57	36	--	--	--	--
Total recycled	1,465	1,560	2,489	3,695	1,675	1,863
Old scrap as a percent of apparent demand	NA	NA	37%	53%	11%	6%
U.S. scrap trade:						
Imports[2]	NA	NA	15	61	508	1,453
Exports	NA	NA	291	655	1,077	840

[1]Returned to the U.S. Bureau of the Mint from material issued for industrial use.
Source: U.S. Bureau of the Mint.
[2]U.S. general imports 1950-70, U.S. imports for consumption thereafter.

Sources of Secondary Silver: There are two sources of recycled silver: old scrap and new scrap. Old scrap results from the acquisition, use, and recycling of products by the ultimate consumer and adds to the supply of silver available in a given year. In 1991, silver recovered from old scrap accounted for 6% of the domestic apparent demand. Apparent demand is a calculated number consisting of the quantity of silver recovered by refineries from ores and concentrates and from old scrap, plus the net imports of refined bullion. It is believed that apparent demand represents not only the quantity of silver required by domestic manufacturers, but also the quantity of silver demanded by U.S. investors.

The other source of recycled silver is new scrap, also called runaround scrap. New scrap is that silver-bearing material or waste remaining after fabricating a new product. It can either be added to new material to continue the manufacturing process, or it can be recycled to produce a new silver-bearing product. Generally it is accepted that new scrap represents an in process flow of the metal, and does not add to supply. Recycling either old or new scrap results in the production of a pure silver bullion. Silver bullion produced from recycled material is indistinguishable from the bullion produced from newly mined material, and is similarly converted into the same shapes, alloys, or chemical compounds.

The recycling of end products has occurred throughout U.S. history. Initially, coinage was the major source of recycled silver. But, growth in the use of silver in consumer goods during the 1950's and 1960's, combined with the removal of silver from circulating coinage, resulted in industrial manufacturing and consumer goods becoming the major sources of recycled silver. Among the major sources of old scrap in 1992 were photographic products such as films and lithographic paper, film developing and processing solutions; electrical and electronic products such as circuit boards; jewelry; and dental amalgams.

The quantity of silver and other precious metals contained in the scrap, and the spot price of these metals determines the price paid for the scrap. Shredding or melting the scrap produces a homogenous material for sampling. Analysis of the samples yields an estimate of the scrap's precious metal content. The seller is reimbursed based on the value of the contained silver and other precious metals less a charge for recovering and refining the metals.

Most silver is recycled using electro-metallurgical techniques. The generalized process involves melting the scrap to remove any organic material and to concentrate the precious metals. After melting, the precious metals are cast into anodes for use in an electrolytic cell. In the electrolytic cell, electrolysis results in the selective movement of the silver from the impure anode to the cathode, where it is removed and cast into pure silver bars.

Outlook: Increasing awareness of the benefits and advantages of recycling should continue to result in the recovery of significant quantities of silver from obsolete products. Through the remainder of the decade, however, the quantity of silver recovered by recycling will remain less than 10% of the domestic apparent demand, owing to events in the late 1970's and early 1980's. Then, silver prices reached their highest levels ever, and large quantities of material with a high silver content such as coins, were recycled. Simultaneously, the high silver prices stimulated manufacturers to find ways to reduce the silver content of their products. This was accomplished and a return to manufacturing these products with a higher silver content is unlikely. The new products meet or exceed the performance of the products they replaced. Therefore, recently manufactured products, as they become obsolete or worn out, will contain less silver per unit than previously; as a result larger volumes of material will be required to recover the same amount of silver. Significantly, there remains a large quantity of silver in the hands of consumers in the form of sterlingware, jewelry, and coins. Consumers hold most of this material for its aesthetic value rather than its silver content. Therefore, this silver is unlikely to be recycled unless there is a significant increase in the price of silver.

Ta

TANTALUM

by Larry D. Cunningham

Tantalum is a refractory metal that is easily fabricated, has a high melting point, is highly resistant to corrosion by acids, and is a good conductor of heat and electricity. Currently, 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, ceramics, columbium, platinum, titanium, and tungsten exist for tantalum but are usually made at either a performance or economic penalty.

Tantalum often occurs in association with tin. Thus, tantalum supply depends significantly on byproduct recovery from tin mining operations. There has been no significant mining of tantalum in the United States since the 1950's. Most domestic resources of tantalum are of low grade and not currently commercially recoverable. Consequently, the United States is highly import dependent for its tantalum raw material supply, and satisfies its tantalum requirements primarily by importing raw materials from Australia, Brazil, and Canada. In 1991, most tantalum products were produced by three companies.

U.S. apparent consumption of tantalum in the form of metal powder, ingot, fabricated forms, and compounds and alloys had the following end uses: electronic components, 62%; transportation, 15%; machinery, 10%; and other end uses, 13%. The value of tantalum consumed in 1991 was estimated at around $120 million.

Recycling of tantalum largely takes place within the processing and product producing industry and is mostly runaround or home scrap that is consumed internally. In addition, quantities of tantalum are recycled indirectly in the form of used tantalum-bearing cutting tools and high-temperature alloy melting scrap. In recent years, the recycling of tantalum in tantalum capacitors from carefully collected and sorted electronic components, has acquired considerable significance. Tantalum in hard metals (carbides for cutting tools) is recoverered by the zinc process, grinding, and acid leaching. Tantalum recovery from tantalum capacitor scrap requires special techniques because of the different types of scrap. Tantalum can be recovered from certain capacitor scrap by electrolysis and acid leaching.

In recent years, consumed tantalum scrap (from various sources) represented an estimated 14% of tantalum apparent consumption (figures 1 and 2). This trend is not expected to change significantly in the future.

Figure 1.

Annual tantalum recycling

(Metric tons, tantalum content)

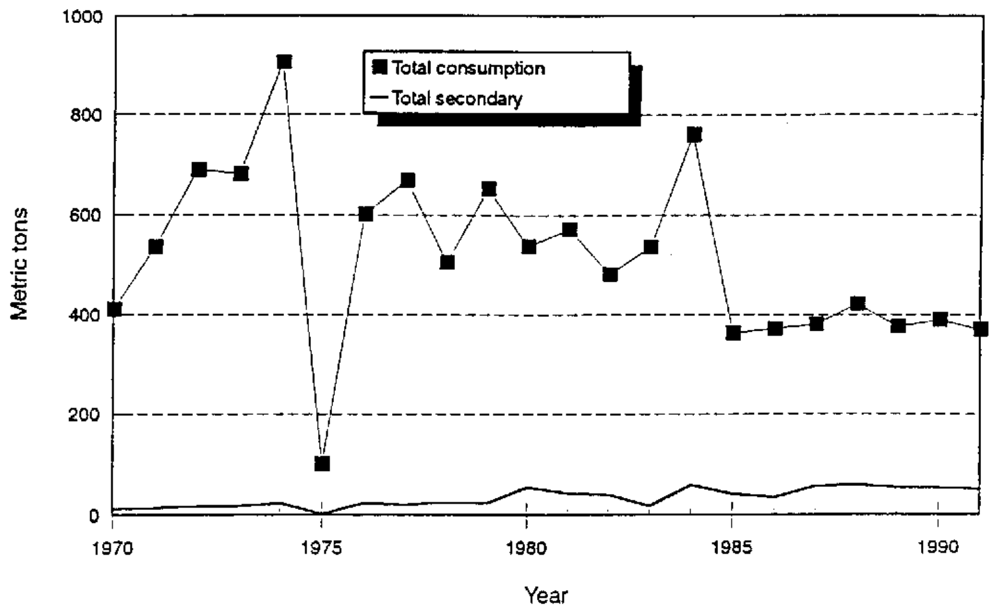
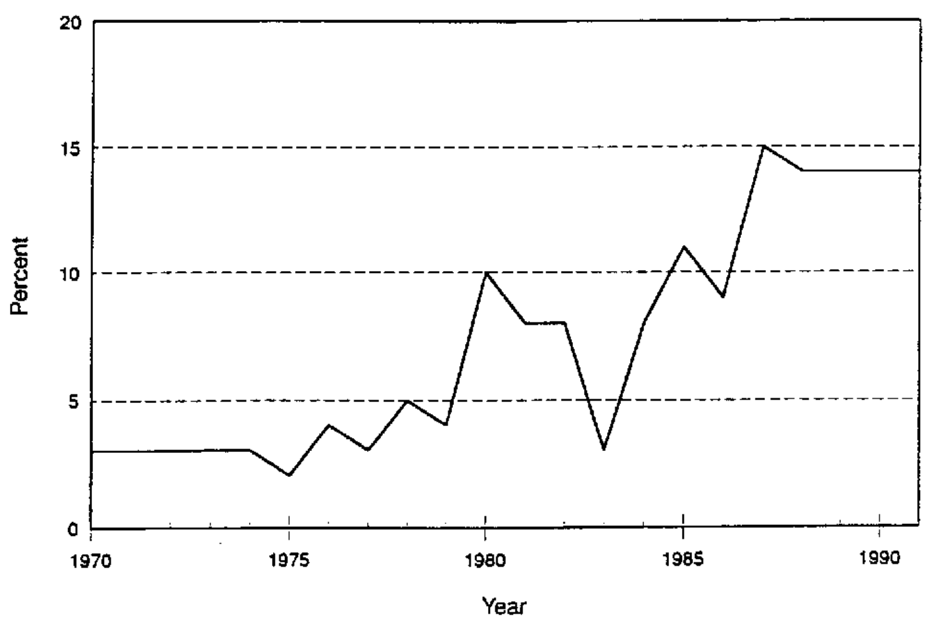


Figure 2.

Annual tantalum recycling

(Total secondary as a percent of consumption)



Sn

TIN

by James F. Carlin, Jr.

Salient Facts: Tin, one of the earliest metals known to humankind, occurs in nature mostly as the oxide mineral, cassiterite. Tin metal is commonly used as a protective coating or as an alloying metal with other metals. Metal is generally used as the starting point for most uses of tin. The major uses for tin are: cans and containers, 32%; electrical, 22%; construction, 10%; transportation, 11%; and other, 25%. Tinplate uses no scrap tin, but most other fabricated end-use items, especially solder and brass-bronze, use substantial quantities of tin scrap.

In 1991 the value of tin scrap consumed was $40 million; in 1991, less than 1% of the tin scrap consumed, valued at $250,000, was derived from imported scrap. No tin scrap was exported in 1991.

Most new and old tin scrap is recycled and recovered. In 1991, an estimated 98% of the new tin scrap generated was recovered and an estimated 96% of the old tin scrap generated was recovered.

Old tin scrap is collected at hundreds of domestic scrap yards, at nine tinplate and can detinning plants, and at most municipal collection centers. New tin scrap is generated mainly in the tin mills at six steel plants, numerous brass and bronze plants, and numerous solder-making plants.

Detinning facilities are unique in the tin scrap industry and nine plants are located across the country. Until about 1989 they processed almost solely new tinplate scrap that originated in the tin mills of steel plants and can-making plants. Since 1989, with new technology that shreds used tin cans, some of the detinning facilities have developed the capability of also detinning old tin cans. Only in the detinning process does free tin metal see its way to the marketplace; all the alloy forms of tin are merely recycled within their own industries and thus reappear as regenerated alloys.

Most tin scrap processing facilities are located close to the tin-using industries and to areas of high-density populations. Most are in the Midwest and Northeast.

Salient Tin Statistics, United States
(Metric tons, tin content)

	1950	1960	1970	1980	1990
Reported consumption	104,464	80,560	73,829	53,362	44,363
Secondary production	33,273	29,030	20,802	12,020	7,747
Secondary production as percent of reported consumption	32	36	28	21	17

Sources of Secondary Tin: Secondary tin is derived 28% from new scrap and 72% from old scrap. New tin scrap consists mostly of forms of tinplate (side scrap, flitters, cobbles, skeletal punch-outs from canmaking, etc.), drosses from soldering, skims, plating residues, and sludges from tinplating lines. Old tin scrap consists mostly of used brass-bronze items (often faucets, fixtures, etc.) and used soldered items (both electronic solders from computers, television and radio sets, and plumbing solders from houses and office buildings); since about 1989, some used tin cans have been detinned and the scrap tin recovered qualifies as old tin scrap.

The solder industry has traditionally consumed large amounts of tin scrap to make solder products; tin scrap accounts for 27% of the total tin used for solder. The brass-bronze industry, while smaller than the solder industry, has also traditionally been a major consumer of tin scrap; tin scrap accounts for 65% of the total tin used for brass-bronze. The relative amounts of tin scrap used have remained fairly steady over the 1950-90 period.

The average life of tin in its end uses is estimated at 20 years. It is estimated that about 10% of the tin placed in use in any year is dissipated in that same year. Tin in such chemical products such as wood preservatives, marine boat hull antifouling paints, fungicides, and tin oxides and tin tetrachlorides sprayed on glass bottles is dissipated quickly. Some longer lasting tin products also release tin to the environment while in use. For example, tinned electrical copper cables lose tin through weathering or corrosion whether overhead or underground. The tin in some other end uses is dissipated, even though the products are disposed of in a controlled way; perhaps recovery was not technically feasible in earlier years. Such an example would be the used tin cans collected by municipal trash departments and placed in landfills during the 1950-90 era; some of those used tin cans located close to the surface or near aerated or moist parts of the landfill depth probably have suffered severe corrosion, while others in the landfill depths may be relatively intact even after decades. Currently, about 12% of the domestic requirement for tin is satisfied by old scrap.

Recovery Methods: Tin recycling processes vary according to the nature of the tin scrap. For tin-plated products, such tinned kitchen trays, tinned electrical copper cables, tinplate, or tin cans, typically the product is treated in a batch process at elevated temperatures with sodium hydroxide solution for a considerable period of time. An electric current is applied in a reversal to the original plating process. The tinned product is made anodic and electrodes in the batch are made cathodic. Positively charged tin ions leave the tinned product and travel through the electrolytic bath to the negatively charged electrode, where the tin is plated and can then be used as scrap tin for a variety of uses.

For tin alloys, generally, there is no attempt to recover the tin as a separate element. Instead, during the alloy refining process in the furnace, periodic chemical analysis tests are conducted and, if needed, additions of tin metal are made to the molten batch to bring the tin content up to desired specifications.

Secondary Products: Secondary tin generally is used in the various alloys of tin, especially brass-bronze and solder. These alloys often take the shape of a bar or ingot, but also sometimes appear as rod or wire, plate, pellets, or powder. Traditionally, the brass-bronze industry uses the largest percentage of scrap tin to total tin.

Scrap Prices and Markets: Scrap prices are generally only available within the industry. But, occasionally, *American Metal Market* publishes some alloy scrap prices and prices for baled tin can scrap.

There is an active market in some forms of tin scrap between countries. Generally, the United States has been the world's leading generator of tin scrap, and in some years substantial amounts are exported.

World Tin Recycling: The United States, along with France, Germany, Japan, and the United Kingdom generally lead the world in tin recycling activity from the standpoint of scrap reclamation innovation, percent of scrap used compared to total metal, and total scrap tonnage. Environmental pressures in these countries for the past 20 years have acted as powerful incentives to recycle. In contrast to the United States and Europe, Japanese industry does little or no detinning since they feel that tin coating weights on tinplate have become so low in the past 15 years that detinning is not economical.

Outlook: The near and long term outlook for tin recycling is positive, with modest growth of less than 1% annually. Scrap is expected to grow from a current 17% of total metal consumed to about 19% by the year 2000. A major incentive is expected to be environmental legislation mostly at the local and State level. If tin prices remain relatively high compared to prices of other major metals, the industry would have sufficient incentive to recycle this costly metal. Secondary recovery is expected to grow at the same modest rate as consumption.

Ti

TITANIUM

by Joseph Gambogi

Salient Facts: Ilmenite and rutile mineral ores are the primary source of titanium for the production of titanium pigments and titanium metal. Over 90% of domestic titanium consumption is in the form of titanium dioxide pigments, while only about 5% of titanium consumption can be attributed to titanium metal.

Applications for titanium metal products are dominated by the commercial and military aerospace markets. About 75% of metal usage is attributed to the aerospace industry; the balance includes chemical process equipment, medical, power plant condensers, marine, and other uses.

The production of titanium metal is carried out in several stages. Titanium ores are chlorinated to produce a chemical intermediate called titanium tetrachloride (tickel). Once purified, magnesium or sodium metal is used to chemically reduce tickel to titanium metal. The crude titanium metal formed by this process is referred to as sponge. Titanium ingot production is derived from melting sponge and scrap metal. Ingot is used to produce a variety of mill products, castings, and fabricated components.

Initially, recycling of titanium scrap was limited because the practice introduced unacceptable contamination in the metal. However, over time, processes were developed that eliminated or reduced these problems. Recycling of scrap began in the 1950's. By the 1960's, the percentage of scrap consumed was above 20% (fig. 1). Since that time, the percentage of titanium scrap consumed to produce titanium ingot has increased significantly. Recent scrap consumption is about 50% of ingot production.

Sources of scrap: Titanium scrap is generated during the melting, forging, casting, and fabrication of components. The majority of scrap is generated in the production of titanium ingot and mill product shapes. Melters generate scrap in the form of solids such as billet cutoffs, bar ends, and plate trimmings. Scrap is also generated as turnings or chips during the turning and shearing of mill products. Forging and casting operations and consumers of mill products generate scrap during component fabrication. Some obsolete or old scrap is recycled from old aircraft components and heat exchangers. Although no data are available as to the percentage breakdown of sources of titanium scrap, it has been estimated that less than 2% of titanium ingot production is derived from old or obsolete scrap.

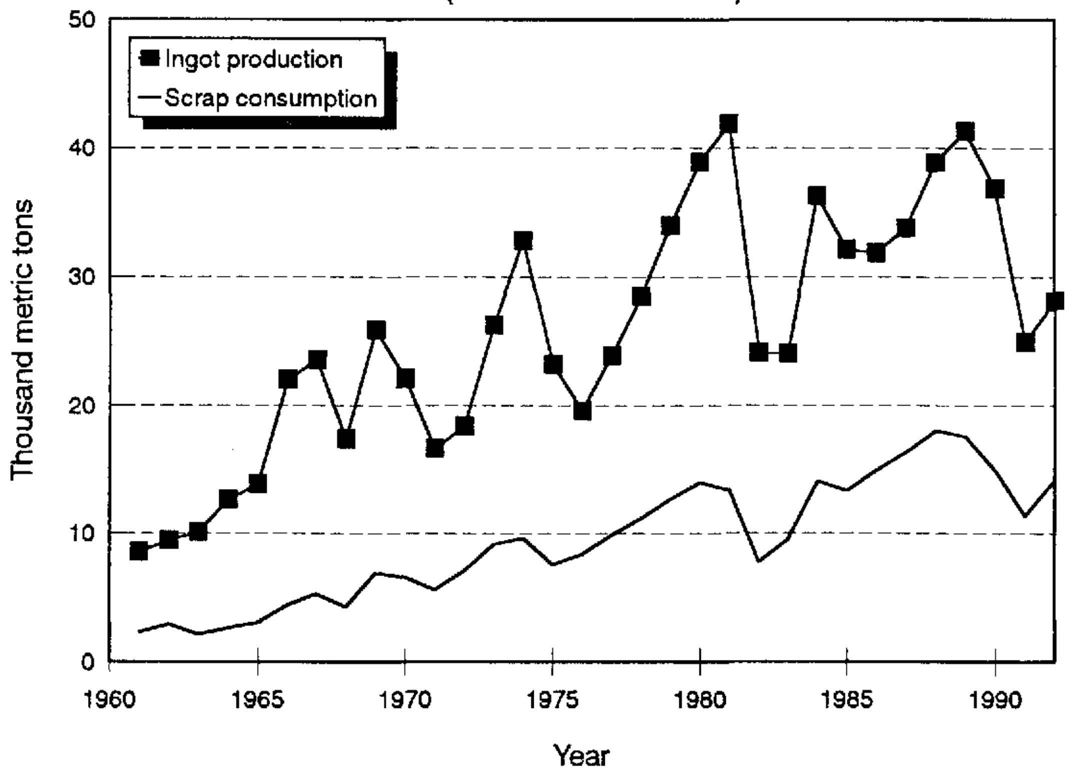
Recovery and Usage: Bulk scrap that is generated in-house by ingot melters is often remelted without difficulties. However, scrap that is to be recycled either in-house or by a scrap dealer must be analyzed, classified, and processed to remove impurities. Scrap turnings are usually contaminated with lubricants, oxides, and carbides. Several companies have proprietary processes to remove impurities.

Titanium scrap is consumed by the steel industry as scrap or it may be converted to ferrotitanium. Consumption is largely derived from the production of stainless steels, where titanium is used as an alloying ingredient or as a gas scavenger.

Titanium scrap is also used to produce aluminum-titanium master alloys for the aluminum industry. Titanium scrap in the form of chemically cleaned turnings is used for this purpose. The aluminum industry adds titanium to aluminum alloys to improve casting and reduce cracking.

Outlook: The continued growth of near net shape castings should have a negative impact on the percentage of material recycled. However, at present, castings do not represent a significant percentage of consumption. The use of cold hearth (plasma or electron beam) furnaces should increase the amount of titanium scrap consumption. Cold hearth furnaces are designed to melt higher percentages of scrap than the traditional vacuum arc reduction (VAR) furnaces. Currently, cold hearth furnaces represent about 25% of domestic ingot melting capacity.

Figure 1.
Production of titanium ingot and consumption of titanium scrap, (1961-1992)
(Thousand metric tons)



W

TUNGSTEN

by Gerald R. Smith

Salient Facts: The excellent cutting and wear-resistant properties of tungsten carbide as well as the unique high-temperature properties of tungsten and its alloys, make it a preferred metal for use in a number of end-use applications. Tungsten carbide powder, compacted and sintered with cobalt powder (cemented carbide), provides a superior metalworking material for machine tool cutting edges, and a wear-resistant surface for metal shaping and forming dies in the manufacturing sector, as well as for drill bits, crushing machinery, and earth-moving equipment in the mining and oil drilling industries. Mill products made from tungsten metal powder are used as filaments and electrodes in lamp and lighting products; as contact surfaces in electrical and electronic equipment; as heavy-metal alloys for radiation shielding, aircraft counterweights, competition darts, and defense-related kinetic energy penetrators; as sheet material for heat shielding applications; as electrodes for inert-gas welding; as electrodes in x-ray and cathode ray tubes; as target material in x-ray equipment; and as resistance coils for high-temperature-furnace heating elements.

To a lesser extent, tungsten is used as an alloy constituent in high-speed steels, tool and die steels, stainless steels, and superalloys to improve properties such as hardness and strength, or resistance to abrasion, shock, and corrosion at elevated temperatures. Nonmetallurgical applications of tungsten include chemicals used in textile dyes, paints, enamels, toners, corrosion inhibitors, fireproofing agents, and catalysts. Additionally, certain tungsten compounds are used as phosphors in pigments, x-ray screens, television picture tubes, and fluorescent lighting.

Recent research results have demonstrated the potential application of tungsten-containing materials in aerospace propulsion systems. Use of chemical vapor deposited tungsten as a wiring medium in advanced semiconductors has also shown exceptional promise. In addition, the technology to produce submicron tungsten carbide powder has progressed to meet the increasing demand for harder, stronger, and more impact resistant cutting and wear-resistant cemented tungsten carbide components.

Use of Secondary Tungsten: Figure 1 shows the domestic use of obsolete tungsten scrap since 1956, in comparison with the apparent consumption of all tungsten materials in the United States. The scrap data represent the quantities reported to the USBM by the U.S tungsten industry, except for the years 1968-74, when these data were estimated. Figure 2 illustrates the quantity of tungsten recycled annually as a percent of apparent domestic consumption of tungsten. A significant portion of this recycled scrap, to be reused in the tungsten industry, is treated by three or four of the major tungsten processors. In 1991, these processors reported to the USBM consumption of 2,150 mt of obsolete tungsten in scrap, valued at an estimated $12.5 million.

Sources of Secondary Tungsten: The extensive use of cemented carbides for cutting and wear-resistant applications, about 64% of U.S. consumption of tungsten, correspondingly generates most of the recoverable obsolete scrap. Of the cemented carbide scrap becoming obsolete each year, it is estimated that as much as 40% is presently being collected, reprocessed, and returned to be reused.

Annual consumption of tungsten as mill products represents about 24% of U.S. consumption of tungsten. The tungsten scrap originating from the resulting mill product end-use items is likely to be internally generated (home) scrap rather than obsolete product scrap. Typically this scrap is recycled within its particular product sector as prealloyed powder. The small quantity that is not recycled in this manner is either added directly in tool steel production or is chemically converted to a tungsten intermediate material for further processing and reuse in other end-product sectors. The source of the mill product scrap generally is from the fabrication-manufacturing stage and includes sinter-bar ends, rod and wire trim, sludge from cutoff wheels, floor sweeps, and rejected parts.

Tungsten consumed as an alloy constituent in ferrous alloys, about 9% of U.S. tungsten consumption, is not amenable to separation and recycling. The obsolete ferrous alloys are generally returned to the steel industry for readdition in steel melts and consequent dilution of the contained tungsten.

Essentially none of the tungsten consumed in nonmetallurgical applications, about 3% of annual consumption of tungsten, is recycled. Factors such as the practicality in collecting the product and the difficulty in separating the tungsten from the product, make it uneconomical to recover the tungsten component and return it for reuse.

Recovery Methods: Direct and indirect, physical and chemical methods are used to recover tungsten carbide from cemented carbides. The methods may or may not involve the removal of the cobalt binder. The two most frequently used physical methods are the zinc process and the coldstream process, both of which provide for direct reuse of the cemented carbide. In the zinc process, developed and patented by the USBM in 1971, molten zinc is initially alloyed with the cobalt-rich phase of the cemented carbide. Upon subsequent removal and recovery of the zinc by distillation, a porous tungsten carbide-cobalt cake remains. The cake is then broken apart, reground, and blended for pressing and sintering into new cemented carbide parts. In the coldstream process, the carbide scrap is entrained in a high-speed flow of air, accelerating the scrap against a hard target with sufficient energy to cause fracture of the scrap material. The resulting shattered material is air classified to recover the finer particles, and the process is repeated as necessary to shatter the remaining larger particles to the desired size. As in the zinc process, the final material is reprocessed into new cemented carbide parts. A third recycling procedure uses a combination of the zinc and coldstream processes. In this combined method, the porous cake produced by the zinc process is shattered using the coldstream process, thereby decreasing the energy expenditure required to produce the desired particle size compared with the individual processes.

Tungsten mill product scrap is typically recycled within its particular product sector as a prealloyed powder. Recycling methods, such as the coldstream process or a chemical oxidation-reduction procedure, are used to prepare the recyclable powder.

Scrap Prices and Markets: Scrap tungsten prices are not quoted on any metal exchange or regularly reported in any newspapers or periodicals. Final prices for scrap transactions are derived through private negotiations between the contracting parties.

Statistics on the values and quantities of imported and exported scrap are reported by the U.S. Bureau of the Census. Based upon these statistics, the value of tungsten in scrap, imported during the period 1965-87, followed a trend generally consistent with and approximating the published prices for tungsten in ore concentrates. The world market price for concentrates during this period ranged from $30 to $160 per metric ton unit of tungsten oxide ($3.78 to $20.18/kg of contained tungsten). The ore concentrate is used as a principal starting feed material in tungsten processing operations. Reported quantities of tungsten scrap imported and exported by the United States for 5 separate years during the period 1956-90 are shown in the following table.

U.S. Scrap Trade
(Metric tons, contained tungsten)

	1956	1960	1970	1980	1990
Imports	150	60	10	180	1,080
Exports	210	250	470	340	290

Scrap containing about 2,435 mt of tungsten, valued at $14.1, was imported in 1991. The amount of tungsten in scrap exported in 1991 was 391 mt, having an estimated value of $7.5 million.

Outlook: According to recent industry estimates, recycled obsolete tungsten scrap actually accounts for about 25% to 30% of current U.S. consumption. By the year 2000, the use of recycled tungsten is expected to rise to about 35% to 40% of total consumption, because the quantity of cemented carbide scrap available for recycling is expected to increase steadily during the next 10 years. Any increase above the estimated 40% annual recovery rate for obsolete cemented carbides, however, will depend to a great extent upon the type of carbide scrap generated. For example, the order of decreasing potential for recovery will be large wear parts (can and wire drawing dies), tool bit inserts, oil drilling bits, and, finally, mining bits. Inherent in any such increase also will be the continuing education of the consumer to be aware of the tungsten values and to avoid unnecessary waste of these values. Another separate, but important, factor affecting an increase in the recovery of cemented carbide scrap will be the market value of the cobalt binder in the cemented carbide components.

Figure 1.

Annual tungsten recycling

(Thousand metric tons, tungsten content)

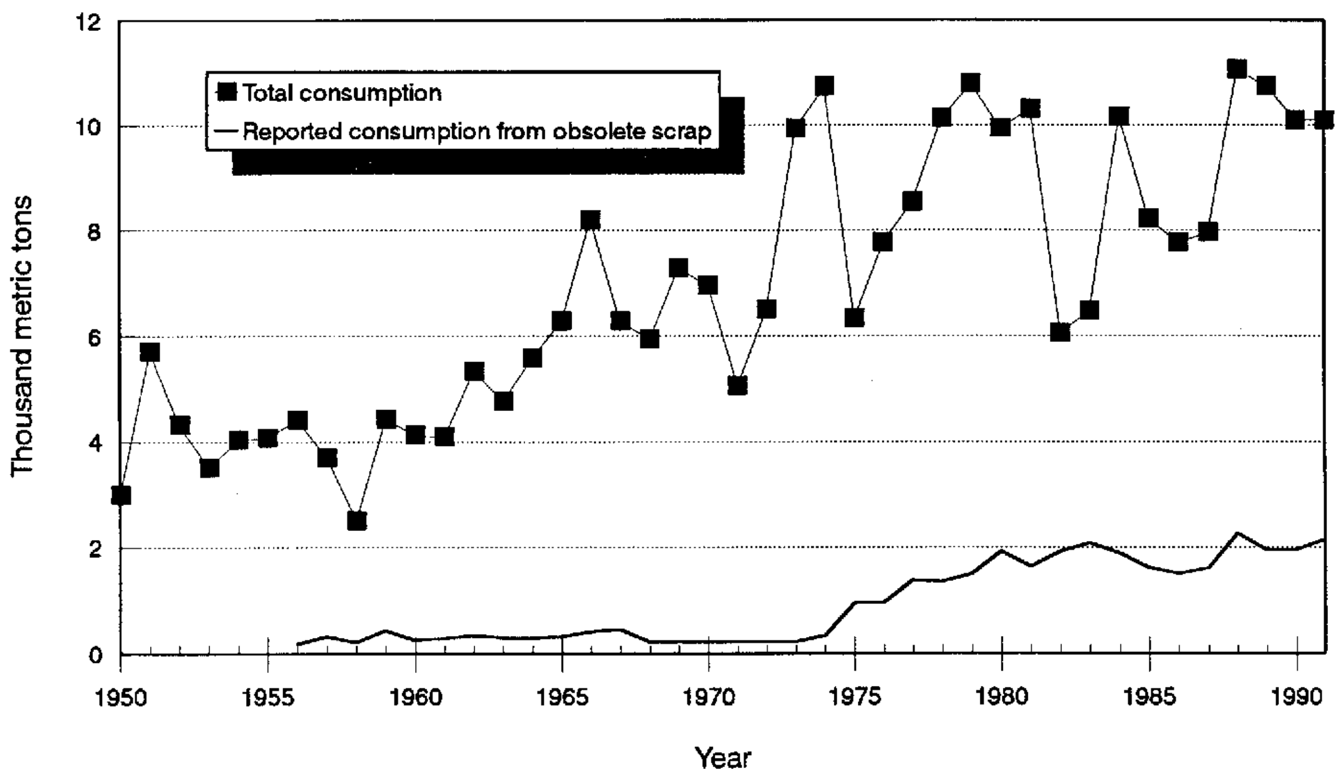
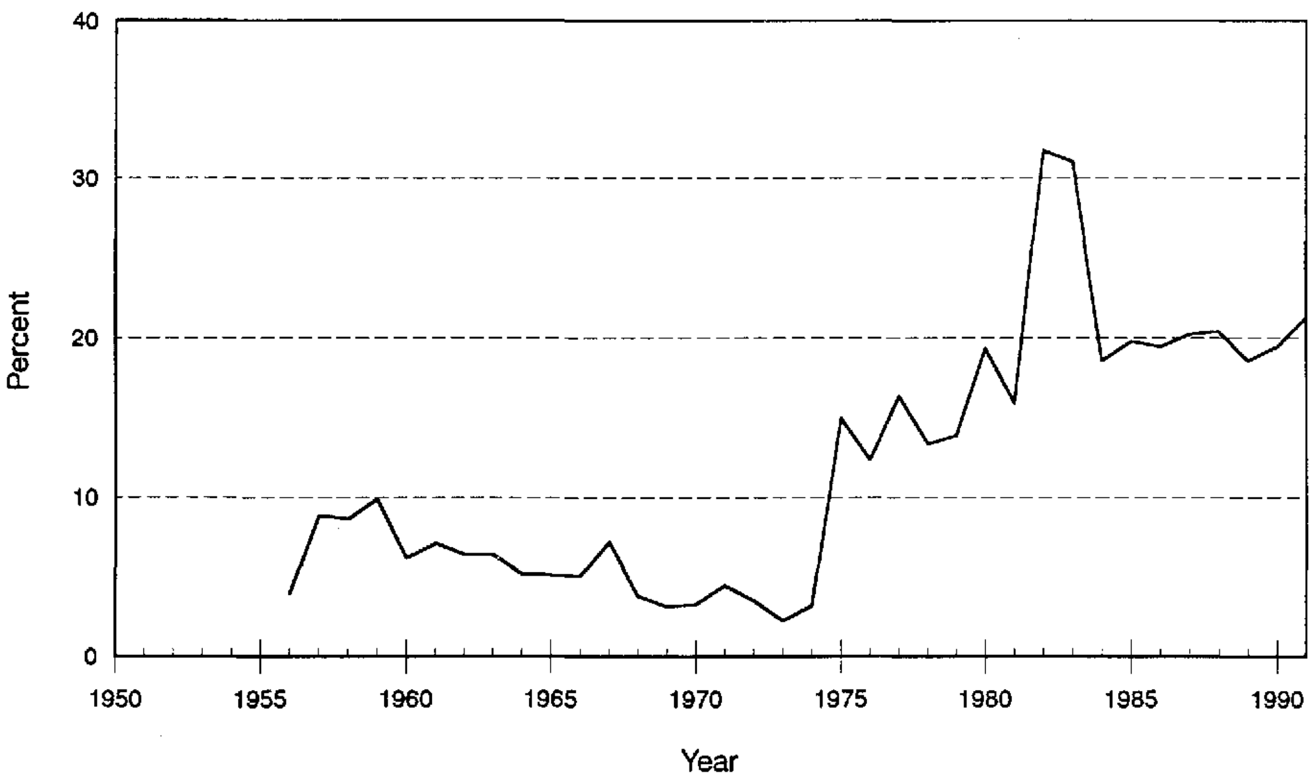


Figure 2.

Annual tungsten recycling

(Total obsolete scrap as a percent of consumption)



V

VANADIUM

by Henry E. Hilliard

Salient Facts: The principal use of vanadium, about 85% of total consumption, is as an alloying element in ferrous and nonferrous alloys. The addition of small amounts of vanadium, often less than 1%, to an ordinary carbon steel can significantly increase its strength and improve both its toughness and ductility. Such high-strength low-alloy (HSLA) steels are used in the construction of highrise buildings, bridges, large-diameter pipelines, and automobiles. Aluminum-vanadium-titanium alloys are widely used in the aerospace industry. Oxides and chlorides of vanadium play an important role in the production of sulfuric acid and other key organic chemicals.

This discussion of vanadium recycling is limited to recovery of vanadium pentoxide (V_2O_5) from spent catalysts in which vanadium is the catalytic material. The recovery of vanadium pentoxide from spent hydroprocessing catalysts that have become poisoned by vanadium, nickel, and other metals during the refining of crude oil is not included. Estimated usage of vanadium in chemical process catalysts and vanadium contained in spent catalyst for the period 1971-91 is shown in figure 1. The estimates are based on selected statistics from the USBM, *Chemical & Engineering News*, and industry specialists. Other vanadium materials and process waste are also recovered and either reused or returned to a primary vanadium producer for reworking, but these are thought to be insignificant when compared to spent catalyst processing.

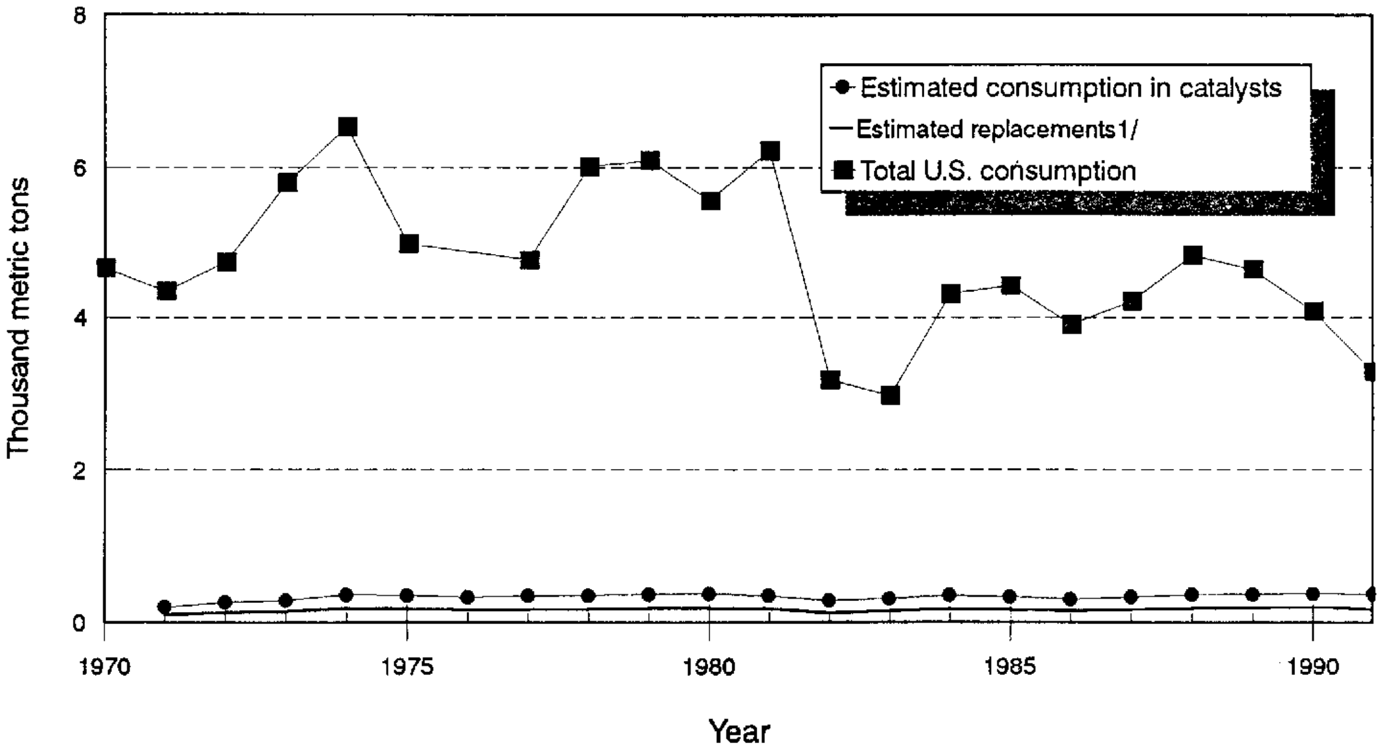
Sources of Secondary Vanadium: The dominant single use of vanadium-bearing catalysts is in the production of sulfuric acid. Catalysts used in the production of adipic acid are a distant second followed by catalysts used to produce rubber and maleic anhydride. Catalytic uses result in very little loss or consumption of vanadium. However, under normal operating conditions, vanadium catalysts slowly lose catalytic activity over time and must be replaced. Typical sulfuric acid plant operations require that first-pass catalyst beds be replaced completely about every 5 to 10 years. Catalyst beds subsequent to the first pass usually can be used for many years if not abused. The need to increase conversion efficiency for pollution control at sulfuric acid plants, the need to expand the capacity of these plants, and the need to build new plants resulted in increased demand for vanadium catalysts in the mid-1970's. Demand was about evenly divided between initial charges to new plants and replacements for spent catalysts. In the period between 1980 and 1990, U.S. sulfuric acid production was flat, indicating that essentially all vanadium catalyst consumption during that period was for replacements. Additionally, first-pass catalysts are typically screened through a mesh annually to reduce dust fouling, and this may result in a make-up requirement of 5% to 10% of the catalysts. Estimated spent catalysts available for recycling vanadium pentoxide is shown in figure 1.

Over the period covered in figure 1, there have been significant changes within both vanadium producing and consuming industries. Gradually, the disposal of waste products in land fills became unacceptable. Under environmental pressure, efforts to reduce or eliminate vanadium discharges in process effluents were initiated. Consequently, the amount of vanadium available for recycling increased from an initial rather low level in 1971. In most applications, significant quantities of spent catalysts and process waste are now recovered and either reused or returned to a primary vanadium producer for reworking. Reports of significant quantities of vanadium recovered from spent chemical process catalysts by primary vanadium producers did not appear until the early to mid-1980's. Actual production of vanadium pentoxide from spent chemical process catalysts is not available and can only be estimated at about 5% of total consumption over the period 1988-91.

Recovery Methods: Each company has developed a process for treating spent catalysts that best suits its needs. While one company may be geared to process silica-base catalysts, another may prefer alumina-base materials. However, a general procedure for vanadium recovery begins by roasting the material with sodium carbonate or some other salt in a multiple-hearth furnace under oxidizing conditions at 560-850° C. Roasting causes vanadium to react with the sodium carbonate to form soluble metal salts. The resulting calcine is quenched in water, ground, and leached with water or dilute sulfuric acid. After solid-liquid separation, vanadium is separated from the leach solution as ammonium metavanadate with ammonium chloride. Finally, the ammonium metavanadate is calcined and fused to produce vanadium pentoxide or used directly to manufacture other vanadium chemicals.

Outlook: Because very little vanadium is lost or consumed in catalytic uses of vanadium, the amount of material available for recycling will most likely remain constant over time.

Figure 1
Consumption of vanadium in catalysts
(Thousand metric tons, vanadium content)



1/Consumption for replacement of discarded spent catalysts.

Zn

ZINC

by James H. Jolly

Salient Facts: Zinc is the fourth most widely used metal after iron, aluminum, and copper. About three-fourths is used in metal form and one-fourth in compound form. More than 90% of the metal is used for galvanizing steel and for alloys; the remainder is used to produce dust, oxide, and various chemicals. Most metal products find widespread use in the automotive, construction, electrical, and machinery sectors of the economy. Compounds are similarly dispersed in distribution and use, but are mainly used in the agricultural, chemical, paint, pharmaceutical, and rubber sectors of the economy. Nearly one-third of the 1.2 Mmt of zinc consumed annually by domestic industries is secondary zinc. In 1991, about 354,000 mt of secondary zinc valued at about $412 million, was recovered in basic forms—refined metal, alloys, dusts, and chemicals. Scrap, containing about 96,000 mt of zinc and valued at $62 million, was exported in 1991, whereas 38,000 mt of zinc in scrap, valued at $19 million, was imported.

Old zinc and brass scrap is collected at hundreds of domestic scrap yards, at more than 200 U.S. automobile and appliance shredding operations, and at numerous municipal collection centers. New zinc scrap is generated mainly in galvanizing plants, diecasting plants, brass mills, and manufacturing facilities when basic zinc materials are consumed. There are 4 primary and 11 secondary smelters that process scrap, drosses, skims, and/or steelworking electric arc furnace (EAF) dust into slab zinc, zinc alloys, and zinc dust. Seven other plants process skims, drosses, scrap, and residues into zinc sulfate and/or chloride chemicals. Secondary brass and bronze are recycled at more than 500 secondary smelters, foundries, and ingot makers. A plant in Illinois produces American-process zinc oxide from oxidic secondary materials. Most secondary zinc plants are in the Eastern and Midwestern United States; one plant in Pennsylvania is, by far, the single largest processor of secondary zinc. Crude zinc concentrates extracted from EAF dust are produced at six plants.

Salient Zinc Statistics, United States
(Thousand metric tons, zinc content)

	1950	1960	1970	1980	1990
Estimated industrial consumption	1,184	1,051	1,426	1,142	1,240
Secondary production	295	241	308	304	341
Secondary production as percent of consumption	25	23	22	27	28
U.S. scrap trade:					
Imports	3	29	2	8	38
Exports	6	11	2	30	109

Sources of Secondary Zinc: Recycled zinc is derived 70% from new scrap and 30% from old scrap. New zinc scrap consists mostly of drosses, skims, furnace dusts, and residues (from galvanizing and diecasting operations, brass mills, and chemical plants) and clippings from the processing (stamping, trimming, etc.) of galvanized steel sheet and strip, rolled zinc, and brass sheet. Old scrap, historically, has consisted almost entirely of diecastings, mainly from scrapped automobiles; brass products; and rolled zinc items, such as gutters, roofing, and engraving plates. Only in the past decade has any zinc been recovered from discarded rubber tires or from old galvanized steel scrap. Zinc recovery from the burning of tires for energy is small but growing, whereas recovery from both old and new galvanized steel scrap has increased dramatically.

New zinc-base scrap, as shown in the following table, has remained essentially unchanged in quantity over the past 40 years despite a sharp drop in zinc used for diecastings; zinc recovery from new galvanized steel sheet scrap, generated mainly in automobile manufacture, has offset declines in scrap generation from diecasting and improved manufacturing processes. Old zinc scrap, on the other hand, has increased substantially in the past few years, owing to the additive effects of zinc recovery from old galvanized steel scrap generated mainly from the shredding of discarded automobiles and appliances.

Common types of zinc scrap have been categorized by the industry such that they are identifiable as to their source and minimum grade and quality requirements. Specifications for the various zinc scrap types were updated by the Institute of Scrap Recycling Industries (ISRI) in 1991 and published by ISRI (1325 G. St. N.W., Washington, D.C. 20005) in *Scrap Specification Circular 1991*.

The life cycles of zinc-containing products vary widely from days, for some chemical products, to more than 100 years for some rolled-zinc and brass products. The average life of zinc in end uses is estimated to be 14 years. Despite recent improvements in the recovery of old zinc, most zinc products are disposed of in landfills or are dissipated into the environment. About 10% of the zinc placed in use in any year is dissipated in that same year. The zinc in such products as fertilizers and animal feeds, oils, inks, pharmaceuticals, vitamins, welding fluxes, and fungicides is dispersed in a relatively short time to the environment and is not recoverable. Many longer lasting products also release and dispense zinc to the environment while in use. For example, galvanized surfaces lose zinc through weathering or corrosion, vehicle tires abrade, paint weathers, and sacrificial anodes are slowly consumed. The zinc in many other end products is dissipated or lost to recycling even though the products are disposed of in a controlled way (placed in landfills) because recovery is not economically, or in some cases not technologically, feasible. Because zinc uses are largely dissipative, the net cumulative rise in total zinc in the overall pool of use in the United States is only 10% to 20% of annual zinc consumption.[1]

Currently about 10% of the domestic requirement for zinc is satisfied by old scrap. In earlier times, the recovery from old scrap was much smaller. This was illustrated in a recent USBM study[1] in which it was estimated that of the 73 Mmt of zinc placed in use in end products in the United States in the period 1850 to 1990, an estimated 23 Mmt (32%) was still in use at the end of 1990, 46 Mmt (63%) had been dissipated, and only 4 Mmt (5%) had been recovered by recycling.

Recovery Methods: Because of wide differences in the character and content of zinc-bearing scrap, zinc recycling processes vary widely. Zinc-containing metals are generally separated from other materials initially by physical means such as magnetics, sink-float, and hand sorting. In the case of mixed nonferrous metal shredder scrap, zinc can be separated from higher-melting metals such as copper and aluminum, by selective melting in a sweat furnace. Zinc in galvanized scrap is largely recovered in furnace dust when the scrap is charged into a steelmaking furnace; however one commercial process has been developed to strip zinc from galvanized scrap with a caustic leach prior to recycling the substrate steel to the steelmaking process.

Clean new scrap, mainly brass and rolled zinc clippings and reject diecastings, generally only require remelting before reuse. Drosses, fragmentized diecastings, and mixed high-grade scrap typically are remelted, followed by zinc distillation with recovery as metal, dust, or oxide. Sometimes, high-purity drosses are simply melted and reacted with various fluxes to release the metallic content; often the recovered metal can be used directly as a galvanizing brightener or master alloy. Medium and low-grade skims, oxidic dust, ash, and residues generally undergo an intermediate reduction-distillation pyrometallurgical step to upgrade the zinc product before further treatment; or, they are leached with acid, alkaline, or ammoniacal solutions to extract zinc, which is subsequently recovered as a compound by precipitation-crystallization or as a saleable chemical retained in solution. Almost all of the zinc in EAF dusts is first recovered in an upgraded, impure zinc oxide product; however, several commercial, EAF-dust-treatment plants are able to bypass the intermediate step and directly recover zinc metal. The upgraded zinc oxide pyrometallurical product mentioned above, is almost always shipped to a primary pyrometallurgical zinc smelter for refinement to metal. For the most part, the zinc metals, alloys, dust, and chemicals recovered from secondary materials are comparable in quality to those derived from primary materials.

The recovery of zinc is very high from simple remelting but declines as the number of processing steps increases and, generally, as the zinc content of the scrap declines. Zinc recovery from most secondary processes ranges between 40% to 85%; however, oxide materials, slags, and residues resulting from initial processes may in turn be recycled, resulting in further zinc recovery.

Secondary Refined Products: Zinc materials made from zinc-base scrap are slab zinc, alloys, dusts, and compounds. Brass scrap, on the other hand, typically, is remelted and, with alloy adjustment, recast as brass. Zinc chloride and sulfate compounds are produced largely by acid leaching of zinc skims, drosses, and chemical residues. Impure zinc oxide products and zinc-bearing slags are sometimes used as trace element additives in fertilizers and animal feeds. Zinc in brass is the principal form of secondary recovery, although in the past few years, secondary slab zinc has risen substantially because it has been the principal zinc product of EAF dust recycling.

Principal Scrap Source Materials and Form of Recovery
(Metric tons, zinc content)

	1950	1960	1970	1980	1990	1991
New scrap:						
Zinc-base	120,499	105,435	119,621	122,654	97,914	118,232
Copper-base	107,523	71,986	119,893	115,909	134,360	114,894
Other	528	1,704	3,044	268	181	181
Total	228,550	179,125	242,558	238,831	232,455	233,307
Old scrap:						
Zinc-base	31,012	34,524	37,426	42,424	86,607	95,206
Copper-base	36,019	26,187	25,281	22,300	21,632	24,320
Other	189	1,312	2,749	808	706	866
Total	67,220	62,023	65,456	65,532	108,945	120,392
Grand total	295,770	241,148	308,014	304,363	341,400	353,699
Form of recovery						
Slab zinc	60,166	61,698	68,450	29,396	95,708	124,078
Brass and bronze	146,413	97,452	148,438	172,040	148,247	127,009
Oxide	12,723	16,038	18,312	31,306	34,726	34,394
Dust	24,459	27,346	26,482	35,557	24,105	22,750
Sulfate	4,243	([1])	8,320	13,195	12,769	23,385
Chloride	11,431	10,881	9,622	10,944	7,436	5,311
Other	36,335	27,733	28,390	11,925	18,409	16,772
Total	295,770	241,148	308,014	304,363	341,400	353,699

[1]Included in other.

Scrap Prices and Price Sources: Prices paid for scrap and secondary materials are generally negotiated, often on the basis of a daily or average London Metal Exchange (LME) price for zinc metal. Bids are required for U.S. Department of Defense scrap sales. Prices depend on factors such as geographic location, quantity available, quality, grade, the presence of other components or elements, and environmental difficulties in handling, transporting, or treating. Zinc and brass scrap prices are generally not available, although average daily, weekly, or monthly prices for a few specific common types are published in *American Metal Market*, *Metal Bulletin*, and *Metal Bulletin Monthly*. Basic guidelines for scrap metal transactions (contracts, packing, weighing, shipping and receiving, rejections, downgrades, and claims) are available in the aforementioned ISRI publication.

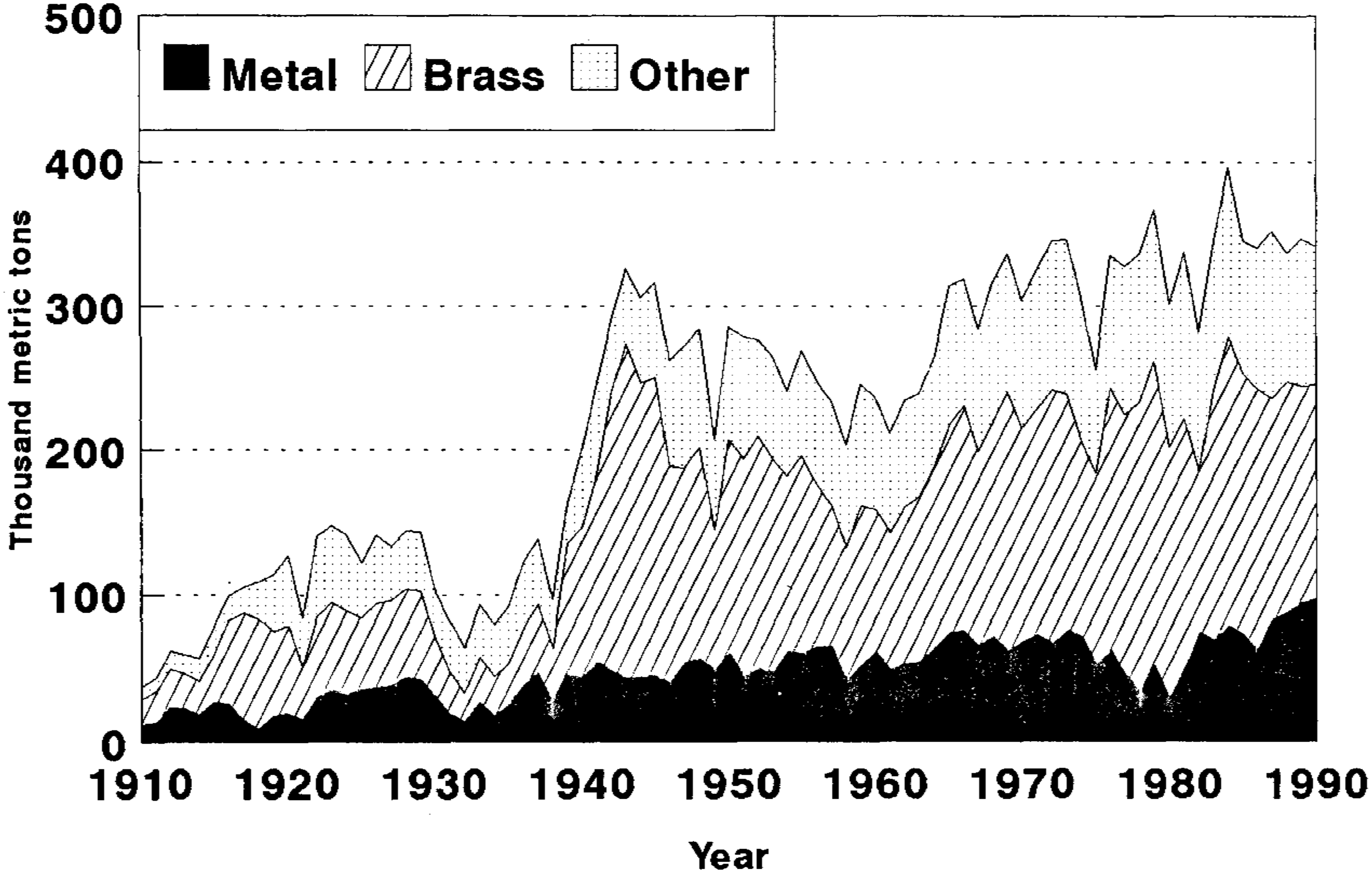
World Zinc Recycling: According to the International Lead and Zinc Study Group, secondary zinc accounted for about 1.9 Mmt or 25% of Western World (i.e. exclusive of the former Eastern Bloc countries for which data is not available) production in 1991.[2] Remelt and direct use of secondary materials for production of zinc dusts, compounds, alloys, and brass, accounted for 78% of the zinc recovered, whereas only 22% was recovered in the form of slab zinc. Based on a report by the European Zinc Institute,[3] the main secondary sources of zinc for recycling in the Western World in 1991 were estimated to be brass scrap, 33%; galvanizing drosses and skims, 22%; die castings, 15%; rolled zinc, 10%; EAF dust, 10%; and other, 10%.

Outlook: Driven by public concern for the environment and legislation intended to protect the environment, both domestic and world secondary zinc recovery is expected to increase as a percentage of zinc consumption in the next decade. However, the prospect for gains higher than 35% to 40% of consumption is relatively poor because of the dissipative nature and diversity of zinc uses. Galvanizing has been the major growth area for zinc, and greater secondary zinc recovery can be expected from this source in the future. Increased processing of low-zinc-grade EAF dust, dust from other steelmaking processes, and energy-generating tire burning appear to be other sources for near term gains in secondary zinc output. Increased zinc recovery from the recycling of carbon-zinc and alkaline batteries, and municipal incinerator dusts and residues are longer term possibilities. Secondary zinc recycling could dramatically increase after 2000 if substantial numbers of electric cars, powered by zinc-air batteries, become a reality.

References:

[1]Jolly, J. H. Materials Flow of Zinc in the United States 1850-1990. BuMines OFR 72-92, 1992, 53 pp.
[2]International Lead and Zinc Study Group. Lead and zinc statistics. V. 33, No. 6, June 1993, 64 pp.
[3]European Zinc Institute. Zinc Recycling. 1992, 12 pp.

U.S. secondary zinc recovery and form (Thousand metric tons)



GLOSSARY OF TERMS COMMON TO METAL RECYCLE

Acid slag. A slag which contains substantial amounts of active silica.

Alloy. A substance having metallic properties and being composed of two or more chemical elements of which at least one is an elemental metal.

Alloying. The process of adding to a metal one or more different elements to form an alloy.

Amalgam. An alloy or compound of mercury with one or more other metals, generally gold and/or silver.

Anode. The positive terminal of an electrolytic cell. Opposite of cathode.

Anode mud; anode slime. A deposit of insoluble residue formed from the dissolution of the anode in commercial electrolysis.

Appraisal. A valuation of scrap and residues by an estimate of an authorized person.

Ashes. Synonymous with skimmings which refers to the oxidized residue skimmed from the top of a bath of molten metal.

Assay. A means of ascertaining the content and commercial value of metals in a scrap or residue material by a fire or wet process. Most often thought of in reference to precious metals, such as gold and silver.

Assay split. Agreed average metal values as between buyer's and seller's assay, used as a pricing basis for the sale of scrap.

Atomization. In powder metallurgy, the dispersion of a molten metal or alloy, often from a scrap source, into particles by a rapidly moving gas or liquid stream. A means of producing a metallic dust, such as zinc or brass dust.

Baghouse. Chamber in which exit gases from roasting, smelting, and calcining are filtered through membranes (bags) which capture the solids and recrystallized volatile components in the form of fine dust. Dusts with sufficient value and those required by legislation are processed to recover valuable metals, including lead, zinc, iron, copper, etc.

Basic slag. A slag low in silica and high in base-forming oxides mainly related to basic steelmaking processes. Such slags are useful as a fertilizer.

Battery breaking. Process of breaking spent batteries, primarily lead-acid types, into pieces sufficient for separation into component parts by various means.

Bottom dross. A zinc and iron alloy formed in a bath of molten zinc in galvanizing iron. The alloy is heavier than zinc and settles to the bottom of the kettle.

Bullion. Uncoined, refined gold or silver in the shape of bars, or comparable masses.

Bundles. Compressed or hand-bundled rectangular bales of scrap metal. Most often used to refer to the shipping form of certain steel scrap. New steel sheet scrap generated by automobile manufacturers is known as factory bundles or auto bundles. Used aluminum and iron cans are commonly compressed into bundles or bales before shipment to the recycler.

Burnt wire. Coated, covered or insulated wire that has been burned to remove the covering. An initial process in preparing copper wire scrap for recycle.

Cakes. Fire-refined copper made from scrap or primary copper cast in a round, cake-shaped mass.

Cathode. The negative terminal in an electrolytic cell. The electrode where reduction occurs. Opposite of anode.

Cathode deposit. Metal precipitated on a cathode by electrolysis.

Chopped wire. Used wire that has been segregated and chopped into small pieces and freed of insulation and other material.

Clips, clippings. Residual metal pieces remaining from the cutting or stamping of metal sheets or strips.

Corrosion. The action or process leading to the gradual destruction of a metal or material usually by solution, oxidation or other means attributable to a chemical process.

Cupellation process. A process step in fire assaying for freeing silver, gold, and other nonoxidizing metals from base metals that can be oxidized. The metallic mixture is placed in a cupel, a shallow porous cup, and roasted in air. The base-metal oxides are absorbed in the cupel, leaving a weighable bead of metal or metals.

Cupola. A cylindrical vertical furnace for melting various metals, especially gray iron by having the charge come into contact with hot metallurgical coke.

Debase. Dilution with less noble or less valuable metal reducing its value.

Detinning. Treatment by chlorination of tin-bearing or tin-coated scrap for recovery of tin as its chloride.

Dissipate. To lose, use up, scatter or dispose of end-use products such that they are not available for collection and recycle.

Distillation. A process of vaporization and recondensation used to separate liquids and metals into various fractions according to their boiling points. In pyrometallurgy, distillation processes are used mainly for metals or metallic compounds which have relatively low boiling points such as mercury, cadmium, and zinc.

Doré. Gold and silver bullion which remains in the cupelling furnace after the lead has been oxidized and skimmed off. It is an intermediate high-grade product that undergoes further refinement. Unparted gold and silver containing over 90% precious metals.

Downgraded scrap. Scrap reduced in value often a result of the presence of lower valued material. In commerce, downgrades occur when the scrap shipment is not in conformity with that specified in the contract.

Dross. The scum that forms on the surface of molten metal largely because of oxidation and sometimes by impurities rising to the melt surface. Drosses when removed from the bath, typically contain entrained bath metal. Also see "bottom dross."

Dust. Micron-sized particles of metal or metallic compounds derived from pulverizing scrap or those carried by furnace gases into flues and settled out. Furnace dusts consist of particles physically carried by furnace gases and volatilzed metallic fumes that crystallize or condense at lower temperatures.

EAF dust. Dust resulting from the melting of scrap in an electric arc furnace (EAF). Generally refers to dust derived from the processing of iron and steel scrap to produce secondary steel.

Electric furnaces for melting and refining metals. Several types of electric furnace are used in the metallurgical industries to melt and/or refine ferrous and nonferrous metal scrap. The chief types are: direct arc, in which the electric current melts the charge by passing through it; indirect arc, in which the heat is supplied by the arc between the electrodes only; and induction heating in which the charge is melted by eddy-currents induced in it by electromagnetic induction.

Electrolyte. A nonmetallic electric conductor, as a solution, liquid or fused solid, in which current is carried by the movement of ions instead of electrons with the liberation of matter at the electrodes.

Electrolytic refining. Suspension of suitably shaped, impure metal ingots as anodes in an electrolytic bath containing alternating cathodes composed of sheets of the same metal to be refined or sheets of a different metal that can be physically stripped of the plated-out metal. Impurities in the anodes collect as insoluble anode slimes or, if dissolved, are systematically stripped from the electrolytic by chemical processes.

Electrowinning. Recovery of a metal in solution, by plating out the metal on a cathode by electrochemical processes.

Fire assaying. Quantitative determination of metals, generally gold, silver, and platinum-group metals, in ores, alloys, and scrap material by separation of the metal or metals from impurities by fusion processes and by weighing the resulting metal to determine the amounts present in the original sample.

Fire refining. Processes used to remove impurities from scrap and impure metals produced by the smelting process. Impurities are removed in the form of gases, drosses, or liquid slags by introducing air into the molten metal or exposing the metal to air, and/or by addition of various fluxes. Cast forms of metal are sold for direct use; however in some cases further refining may be necessary.

Flue dust. Dust captured in the flues of smelters and other furnaces. It is composed of volatilized, oxidized metals such as arsenic, zinc, bismuth etc. and nonvolatized carryover dust particles.

Flux. A substance that promotes the fusing, melting, and refining of minerals, metals, or scrap by aiding in the removal of undesirable materials and impurities by forming a slag; preventing the formation of metal oxides; and/or lowering the melting point of the charged material.

Fly ash. Fine solid particles of noncombustible ash carried out of a bed of solid fuel by the draft.

Fume. Metals and metallic compounds that have been volatilized at high temperatures in a furnace and subsequently, crystallize or condense at lower temperatures in flue gases that exit the furnace. Particles are typically sub-micron in size.

Grindings. Particles of scrap metal resulting from the sharpening, wearing away, or shaping of metals by files, grindstones, etc.

Hand sorting. Manual removal of selected materials from unsorted scrap and wastes.

Hard lead. Metal in which the high degree of malleability characteristics of pure lead is reduced by the presence of impurities.

Hard zinc spelter. Bottom dross in galvanizing operations.

Hockey puck. Small pressed scrap form for use in remelting furnaces. So named because the shape resembles a hockey puck.

Home scrap. Process scrap generated and used in the same plant.

Hydrometallurgy. The treatment of ores and other metal-bearing materials by wet processes, usually involving the solution of some component and its subsequent recovery from the solution.

Landfill. A controlled system of trash and garbage disposal in which commercial and municipal waste is buried between layers of earth resulting in the filling of pits or build up of low lying lands.

Leaching. The process of extracting soluble metallic compounds from residues, dusts, and scrap by selectively dissolving it in a suitable solvent, such as water, cyanide, acid, etc.

Liquation. The process of separating by heat a fusible substance from a substance less fusible. Also see sweating.

Magnetic separation. The separation of magnetic materials generally iron, from nonmagnetic metals and materials.

Master alloy. An alloy rich in one or more desired addition elements that can be added to the melt to raise the percentage of the desired element.

Matte. A crude metallic sulfide mixture formed in smelting sulfide ores and certain scrap materials. In smelting scrap lead-acid batteries, iron is added to the charge to combine with the sulfur in lead sulfate forming a matte.

Mill scale. The scale of ferric oxide that peels from iron and steel during rolling.

New scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption including all defective finished or semifinished articles that must be reworked. Examples of new scrap are clippings, turnings, borings, skims, drosses, and defective castings.

Obsolete scrap. Same as old scrap.

Old scrap. Scrap consisting of metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, silver from photographic materials, metals from shredded cars and appliances and used aluminum beverage cans.

Paste desulfurization. Recycling processes used to separate sulfur and lead in lead sulfate paste occurring in spent lead-acid batteries. Typically sodium carbonate in solution is employed to form insoluble lead carbonate and soluble sodium sulfate which are then separated. The lead product is suitable for lead extraction by standard technology.

Pickle. An acid dip used to remove oxides and other compounds from the surface of a metal by chemical reaction.

Pickling. The process of chemically removing scale or oxide from metal objects to clean them or to obtain a chemically clean surface prior to galvanizing, plating, or painting.

Processing liquors. Liquid chemicals and water that were used in processing, and refining metals. May contain high metal content and be suitable for metal recovery.

Pot heels. Bottom dross buildup in lead drossing kettles, typically, return as home scrap to the lead blast furnace.

Purchased scrap. All scrap that enters any plant in any form, whether new or old, and includes scrap treated on a toll basis or conversion agreements and interplant transfers of scrap.

Pyrometallurgy. Metallurgy involved in the winning and refining of metals where heat is used, as in roasting and smelting.

Remelt. Scrap metal that is melted and used without further refinement, except that contaminants and drosses are removed. In some cases, as in remelt brass, alloying components can be added to bring the melt up to specifications.

Recycle. The process of restoring to usefulness partially or wholly, a nonuseful product or material or some component of the nonuseful product or material.

Refining. Process in which a metal is made free from impurities; to purify a particular metal.

Refining kettle. An open-top vessel used in carrying out metallurgical operations on low-melting-point metals; for example, in drossing and desilverizing lead.

Residue. That which remains after a part has been separated or otherwise treated or that metal or compound necessary in a chemical process but which remains in the nonproduct portion of the process waste stream.

Retort. A vessel used for the distillation of volatile materials as in the separation of some metals, such as mercury and zinc, or for distilling mercury in an amalgam to recover gold.

Run-around scrap. Same as home scrap.

Sal skimmings. Chlorine-bearing skimmings from the surface a galvanizing bath when fluxs are used to coat steel after pickling.

Scrubber. Device used to separate soluble gases with extracting liquids, chemical reactions, and/or to remove dust from flue gases by washing.

Secondary metals. Metals and alloys recovered from scrap and residues. Distinguished from primary metals, which are derived from ores. Secondary refers only to the source of the metal and has no relationship to the type of product recovered either as to quality or physical characteristics.

Secondary smelter. Term used to describe plants that entirely or principally treat scrap and secondary materials to produce refined metals and alloys. In copper, applies only to those plants producing a product for further refining.

Shredder. A facility that rips and tears into small pieces obsolete products such as automobiles and appliances, and one that usually has equipment to separate the resulting fragments into magnetic metal, non magnetic metal, glass, and other fractions suitable for recycle or disposal.

Shredder fluff; shredder residue. Fibrous and other organic materials resulting from the shredding of automobiles and other products.

Sink-float separation. Separation of heavy and light components in a mixture by immersion in a fluid bath of intermediate density. Heavy material sinks and light material floats. The heavy media or bath can be water, a homogenous liquid, or a finely ground slurry of appropriate heavy material, such as ferrosilicon, magnetite, or barite, in water.

Skims; skimmings. See ashes.

Slag. The top layer of a multilayer melt formed during some smelting and refining operations. It generally consists of silicates and aluminosilicates, lime, and other bases which separate from mattes and metallic products in smelting operations. In scrap metal refining, slags contain the oxidized impurities. Most slags from scrap recycle procedures are considered to be by-products and are sold as commercial products.

Slime; slimes. See anode mud.

Smelting. Process involving heat to melt and fuse ores and scrap materials with chemical changes to separate metals from impurities. Simple melting is not considered a smelting process.

Superalloy. An alloy, generally either nickel-base, cobalt-base, or iron-base and containing one or more of the following elements—chromium, cobalt, columbium, manganese, molybdenum, nickel, titanium or tungsten—developed for high temperature service where relatively high stresses are encountered and were oxidation resistance is frequently required.

Swarf. A mixture of fine metallic and abrasive particles removed by a cutting or grinding tool. May also be chippings and shavings from soft iron castings which are sometimes used as a reducing agent in various chemical syntheses.

Sweated pig. A crude casting of metal extracted by sweating scrap. For aluminum, it is a special category of old scrap resulting from the differential melting of aluminum attached to iron or other ferrous scrap. Sweated pig is considered to be an intermediate product, which must be remelted and blended with other aluminum to produce specification ingot.

Sweating. A furnacing method involving controlled heating to separate lower-melting-point metals from higher-melting-point metals in mixed nonmagnetic metal scrap generated mainly by shredder operations. Zinc, for example, has a lower melting point than aluminum, copper, and stainless steel. It will liquify first and is allowed to run out of the furnace into a mold. Aluminum is next sweated out, leaving copper and stainless both of which are generally not melted in this process.

Toll refining. Term used when a customer pays an agreed fee to a smelter or refinery for refining service without loss of ownership of the metal recovered.

Turnings. Scrap metal chips and shavings generated during lathing, milling, or chiseling.

UBC. Used beverage cans. Refers mainly to cans made of aluminum and steel.

Upgrade. To increase the specific metal content, quality, and/or value of scrap.

Zinc Process. A method that uses molten zinc to disintegrate superalloy and cemented carbide scrap to assist recycling.