U.S. Department of the Interior
U.S. Geological Survey

Germanium Recycling in the United States in 2000

By John D. Jorgenson

U.S. GEOLOGICAL SURVEY CIRCULAR 1196–V

FLOW STUDIES FOR RECYCLING METAL COMMODITIES IN THE UNITED STATES

FOREWORD

As world population increases and the world economy expands, so does the demand for natural resources. An accurate assessment of the Nation's mineral resources must include not only the resources available in the ground but also those that become available through recycling. Supplying this information to decisionmakers is an essential part of the USGS commitment to providing the science that society needs to meet natural resource and environmental challenges.

The U.S. Geological Survey is authorized by Congress to collect, analyze, and disseminate data on the domestic and international supply of and demand for minerals essential to the U.S. economy and national security. This information on mineral occurrence, production, use, and recycling helps policymakers manage resources wisely.

USGS Circular 1196, "Flow Studies for Recycling Metal Commodities in the United States," presents the results of flow studies for recycling 26 metal commodities, from aluminum to zinc. These metals are a key component of the U.S. economy. Overall, recycling accounts for more than half of the U.S. metal supply by weight and roughly 40 percent by value.

Charles G. Groat
Director

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FIGURES

TABLE

CONVERSION FACTORS

Multiply	By	To obtain
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t, 1,000 kg)	1.102	ton, short (2,000 lb)

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ABSTRACT

This report describes the recycling flow of germanium in the United States in 2000, as well as other germanium material flow streams. Germanium was recycled mostly from new scrap that was generated during the manufacture of germanium-containing fiber optic cables and from new and old scrap products of germanium-containing infrared imaging devices. In 2000, about 11.5 metric tons of germanium was recycled, about 40 percent of which was derived from old scrap. The germanium recycling rate was estimated to be 50 percent, and germanium scrap recycling efficiency, 76 percent.

INTRODUCTION

This materials flow study of germanium includes a description of germanium supply and demand factors for the United States in 2000 to illustrate the extent of germanium recycling[1] and to identify recycling flows. Figure 1 shows the germanium recycling flow and the distribution of domestic supply of primary and secondary germanium in 2000.

Although predicted to exist in 1864, germanium was not discovered until 1886 (Butterman and Jorgenson, 2005, p.1). It is a hard, brittle semimetal that first came into common use in the 1950s as a semiconductor material in radar units and as one of the materials from which the first transistor was made. Today, it is used principally as a component of the glass used in telecommunication fiber optics; as a polymerization catalyst for polyethylene terephthalate (PET), which is a commercially important plastic; in infrared night vision devices; and as a semiconductor and substrate in electronics circuitry.

Salient germanium statistics, presented in table 1, are based mostly on the germanium content of fiber optic materials, polymer catalysts, and electrical/solar panels. In 2000, about 8.7 metric tons (t) of germanium contained in old scrap was generated, and about 4.6 t of germanium valued at about $6 million was consumed. The old scrap recycling efficiency was calculated to be about 76 percent, and the recycling rate, about 50 percent. Germanium contained in new scrap consumed was about 6.9 t.

[1]Definitions for select words are found in the Appendix.

Table 1. Salient statistics for U.S. germanium scrap in 2000.

[Values in kilograms, contained germanium, unless otherwise specified]

Old scrap:	
Generated[1]	8,700
Consumed[2]	4,600
Consumption value[3]	$6 million
Recycling efficiency[4]	76 percent
Supply[5]	9,200
Unrecovered[6]	2,200
New scrap consumed[7]	6,900
New-to-old-scrap ratio[8]	60:40
Recycling rate[9]	50 percent
U.S. net imports of scrap[10]	1,900
Value of U.S. net imports of scrap	$2.4 million

[1]Germanium content of products theoretically becoming obsolete in the United States in 2000. It excludes dissipative uses.

[2]Germanium content of products that were recycled in 2000.

[3]Unit value of contained germanium in materials used in calculating total value of contained metal in scrap.

[4](Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imported).

[5]Old scrap generated plus old scrap imported.

[6]Old scrap generated plus old scrap imported minus old scrap consumed minus old scrap exported.

[7]Including prompt industrial scrap, but excluding home scrap.

[8]Ratio of quantities consumed, in percent (see appendix).

[9]Fraction of the germanium apparent supply that is scrap, on an annual basis.

[10]Trade in scrap is assumed to be principally in old scrap.

GLOBAL GEOLOGIC OCCURRENCE OF GERMANIUM

Germanium is a dispersed element. It occurs in trace amounts in many minerals, which include some of the common metallic ore minerals. In nature, it never exists as the native metal and is rarely found in commercial quantities in the few minerals in which it is an essential component. In the crystal lattice of such minerals, it substitutes for arsenic, gallium, silicon, tin, zinc, and other elements. In coal, germanium is associated with the organic rather than with the mineral component of the seams (Plunkert, 1985; Brown, 2002).

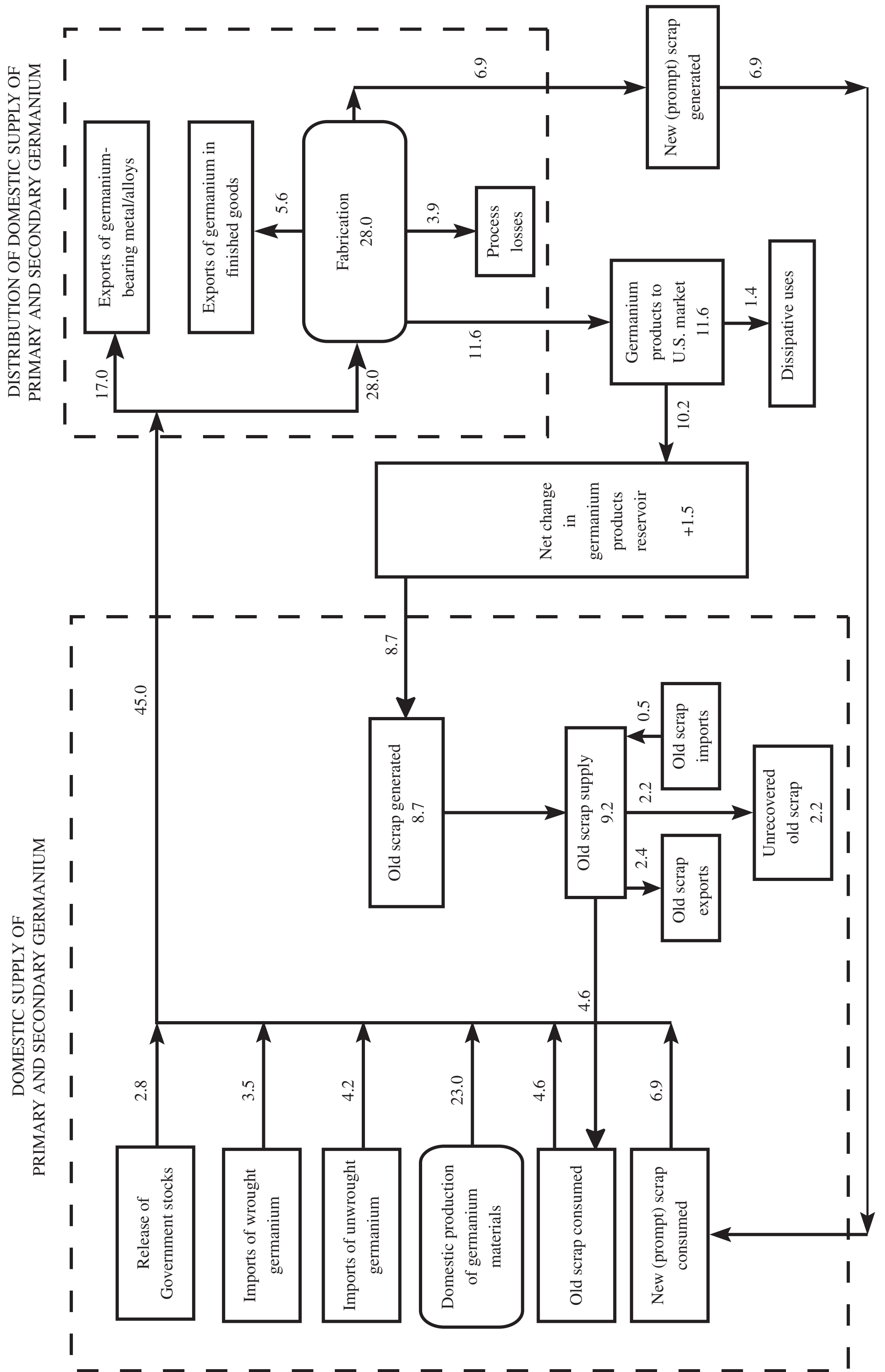

Figure 1. U.S. germanium materials flow in 2000. In metric tons of contained germanium.

The mean germanium content of the Earth's crust lies in the range of 1.0 to 1.7 parts per million (ppm) and is usually placed at 1.4 or 1.5 ppm. Its mean concentration in igneous rocks is 1.0 to 1.6 ppm and in sedimentary rocks, excluding coal, 0.4 to 2.2 ppm; in some coals, its mean concentration is about 5.5 ppm (Weeks, 1973; Bernstein, 1985).

Ore deposits in which germanium is found are characterized by abundant base metals, especially zinc and copper. The most commercially important germanium-bearing ore deposits are zinc or lead-zinc deposits formed at low temperature, such as those in the Tri-State District of Kansas, Missouri, and Oklahoma and in the upper Mississippi Valley region. Some complex copper-arsenic-antimony-tin deposits, such as those at Butte, Mont., and Chuquicamata, Chile, also contain significant germanium, although it is not always recovered (Butterman and Jorgenson, 2005, p. 4-5).

Weeks (1973) listed 15 ore minerals in which germanium is present locally. The most important and widespread of these germanium occurrences are in the zinc sulfide minerals sphalerite and wurtzite (both ZnS) and less commonly in the copper minerals bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), enargite (Cu_3AsS_4), and tennantite ($Cu_{12}As_4S_{13}$).

Most of the world's supply of germanium is a byproduct of zinc smelting and a smaller amount derived from copper smelting; both sources reflect an origin in sulfide ores. Some germanium has also been extracted from fly ash at coal-burning powerplants in China, the United Kingdom, and the Commonwealth of Independent States.

In the United States, reserves of germanium are located mainly in the zinc deposits of the Red Dog District of Alaska; lesser amounts are found in the zinc ores of central Tennessee.

PRODUCTION AND PRODUCTION PROCESSES

Germanium is produced in the United States as a byproduct of base-metal mining, especially zinc, and as secondary product from scrap and waste. Germanium also has been recovered from mines that produce a germanium concentrate. In other countries, germanium also is recovered from fly ash, which is a product of coal combustion. All concentration of germanium is performed in other countries. Until recently, Pasminco Limited (Australia) mined germanium-bearing ores at its Gordonsville Mine in Tennessee. Pasminco sent a germanium-bearing concentrate from the Clarksville refinery in Tennessee to Belgium for further processing. (The Gordonsville Mine was closed in 2003, and no germanium-bearing materials are being produced.)

The Red Dog Mine of Teck Cominco Limited (Canada), located in northwestern Alaska, produces a germanium-bearing concentrate. This concentrate is sent to Teck Cominco's Trail complex in British Columbia for processing. A large portion of the recovered germanium is converted to a germanium dioxide (GeO_2) solution and shipped to Japan as PET catalyst to be used in the plastic bottling industry.

The products of the different recovery processes that produce a germanium-bearing material are refined into the major germanium products—germanium tetrachloride ($GeCl_4$), GeO_2, first reduction metal, zone-refined metal, and single crystals. Germanium tetrachloride is distilled in a chlorinated environment from germanium-bearing residues and concentrates dissolved in hydrochloric acid. A series of fractional distillations then further purifies the crude tetrachloride.

Germanium dioxide is produced by the filtration and vacuum-baking of germanium hydroxide, which, in turn, is produced from hydrolysis of purified $GeCl_4$. The burning of germanium disulfide can also be used to produce GeO_2.

A first reduction metal is produced by burning GeO_2 with hydrogen in a reducing environment. This produces a metal powder, which is melted and cast into ingots.

To produce an ultrapure germanium metal, which is used in electronic applications and for the production of single crystal germanium, first reduction germanium metal is "zone refined." Passing the ingot through a series of induction coil heaters produces zone-refined polycrystalline germanium, which is the most widely traded germanium product. As the bar melts and resolidifies, the impurities are concentrated in the molten zone. The end of the bar that contains the impurities is then removed for reprocessing.

Single-crystal germanium, which is used in many critical electronic and infrared fiber optic applications, can be produced by two different processes. The vertical pulling process involves dropping a monocrystalline seed into molten germanium, rotating the crystal to maintain uniform temperature, and drawing the crystal slowly up through the melt as it is cooled. The horizontal pulling process entails the creation of a molten zone, which moves along from a monocrystalline seed to a polycrystalline rod lying in a graphite boat (Roskill Information Services Ltd., 1990; Thomas, 1997, p. 545-547).

USES

Germanium has the following principal end uses: in the glass in telecommunication fiber optics, as a polymerization catalyst for PET, in infrared night vision devices, and as a semiconductor and substrate in electronics circuitry. In 2000, estimated end uses for germanium in the United States were fiber optic systems, 50%; polymerization catalysts, 20%; infrared optics, 15%; electronics/solar electrical applications, 10%; and other uses (mainly phosphors, metallurgy, and chemotherapy), 5% (Brown, 2001). U.S. germanium consumption from 1981 through 2000 is shown in figure 2.

Germanium owes its usefulness to at least five salient properties. First, as an intrinsic semiconductor, it will conduct electricity in the pure state, albeit poorly. Germanium is particularly effective as a semiconductor at high frequencies and low operating voltages. Second, germanium is transparent in the crystalline and glassy states to part of the infrared spectrum. Third, like silicon, it forms glass and is able to form

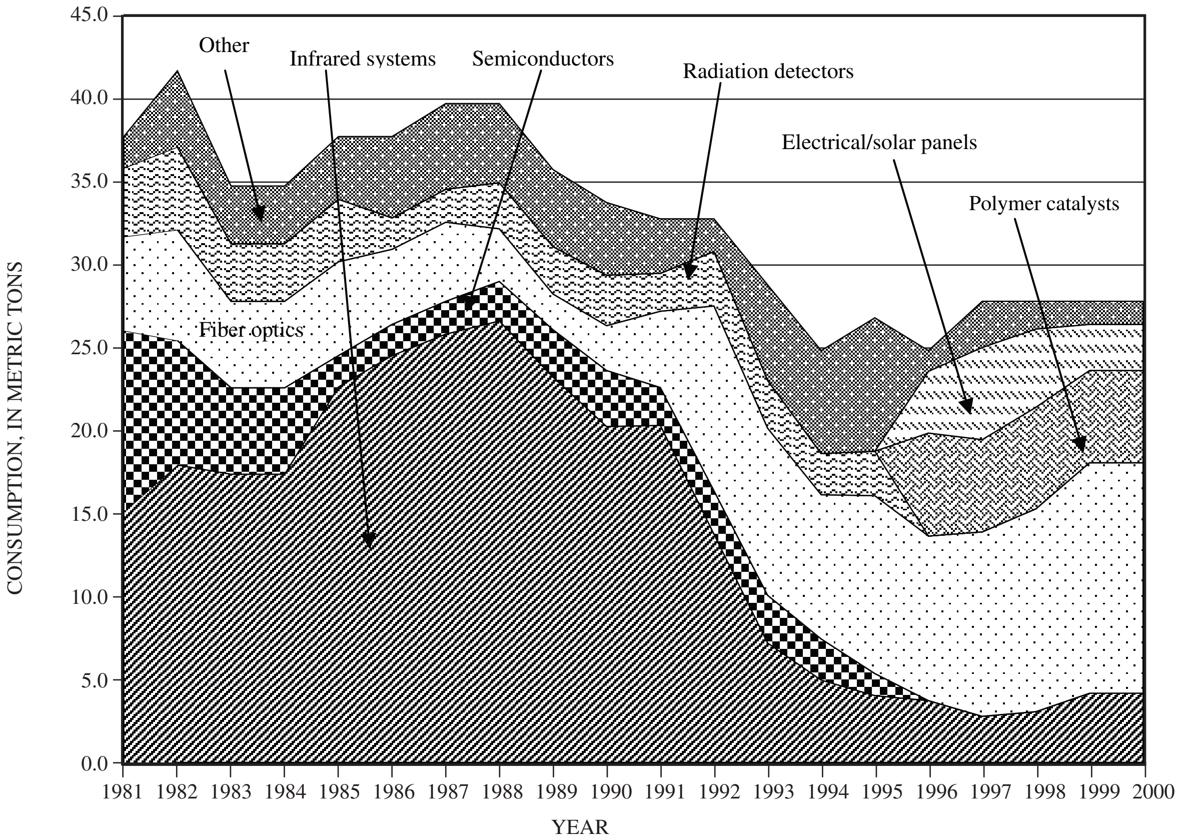

Figure 2. U.S. germanium consumption, by end-use sector, from 1981 through 2000.

extended three-dimensional networks of germanium-oxygen tetrahedra that lack the long-range order of crystalline substances. Fourth, it has an exceptionally high refractive index. And, fifth, it exhibits low chromatic dispersion. These five properties, singly and sometimes in combination, determine the usefulness of germanium in electronic devices, solar power arrays, night vision devices, optical lens systems, and fiber optics. A sixth property, which is specific to a single but commercially important use, is the ability of germanium to catalyze the polymerization of PET without undesirable coloring of the plastic product.

Optical fibers are formed by the modified chemical vapor deposition process in a series of three stages. First, a hollow silica tube is heated, and a mixture of oxygen and germanium- and silicon-tetrachloride is passed through it; this process deposits a glass "soot" on the interior of the tube. Second, the temperature is increased, and the glass collapses into a "preform." In the third and final stage, the preform is further heated and pulled into a thin optical fiber. Several of the advantages of the new technology of fiber optic communications compared with the old copper-wire technology include immunity from electrical interference; no crosstalk; fibers act as insulators even in high-voltage areas; bandwidths are increased to several gigahertz; the size and weight of cables are greatly increased, which improve ease of installation; and only a single fiber is required compared with the two-way circuit required to complete copper-wire-based communications (Crisp, 2001).

PRICES

In the mid-1970s, electronic-grade silicon substituted for germanium in diodes, rectifiers, and transistors. The resulting loss in germanium demand, however, was more than offset by its increased use in fiber optic communication networks and infrared night vision systems. The net increase in germanium demand led to tight supply and a surge in prices.

Events that had some impact on the price of germanium during the 1990s included vigorous demand for fiber optics in the telecommunications sector, growth in the use of germanium as a catalyst in PET, discovery of additional practical uses for infrared technology, and sales of germanium from the National Defense Stockpile (Brown, 1999). Increased use of germanium as a polymerization catalyst in PET, continued growth in fiber optic applications, and production shortages led to a significant spike in the germanium price in 1996. The telecommunications industry was experiencing strong growth, which was demonstrated by the increasing use of germanium in fiber optic applications. The releases of germanium from stockpiles in Russia, Ukraine, and the United States that resulted from a lowering of world military tensions stabilized the price of germanium by the end of the decade.

Zinc mineral concentrates from some mines are the primary source of germanium, and the price for germanium products can be significantly affected by zinc production. In spite of this association with zinc, the price for germanium products generally follows the demand for the end use products in which it is consumed. The price of germanium metal products also depends on purity.

Figure 3 shows trends in the annual average price of germanium from 1981 to 2000. Between 1994 and 1996, the price for zone-refined germanium almost doubled (in constant dollars), and production could not meet market demand, which resulted in sustained inventory reduction.

Not until 1995 were domestic producer prices for germanium metal and set higher than the until-then-record-high price levels established in late 1981, which were $1,060 per kilogram and $660 per kilogram, respectively. From 1981 to 1995, domestic producers significantly discounted prices in response to competition from imported materials. Producer prices for zone-refined germanium reached $1,375 per kilogram in 1995 and $2,000 per kilogram in 1996. Producer prices for GeO_2 rose to $880 per kilogram in 1995 and $1,300 per kilogram in 1996. By 1997, the producer prices had fallen back to $1,475 per kilogram for the metal and $950 per kilogram for GeO_2. In 1998, prices increased again to $1,700 per kilogram for germanium metal and $1,100 per kilogram for GeO_2. In 1999, prices were reduced to $1,400 per kilogram and $900 per kilogram, respectively, owing to sluggish demand. In 2000, prices continued to fall, reaching $1,250 per kilogram for germanium metal and $800 per kilogram for GeO_2, mainly owing to plentiful supply rather than lack of demand.

Free market prices for GeO_2, as published in Metal Bulletin, began 2000 in the $680-to-$750-per-kilogram range and ended the year in the $620-to-$700-per-kilogram range. The price for Belgian-produced GeO_2, as published in Metal Bulletin, remained at $750 per kilogram all year.

In 1998, germanium prices increased despite an oversupply (a result of slight decreases in world demand for optical fibers and PET) and an increase in total supply (owing to greater amounts of recycling and continued releases of germanium from national stockpiles in Russia, Ukraine, and the United States). This increase in price probably was owing to anticipated increase in demand in the satellite communications sector. In 1999, when demand did not increase, germanium prices began to fall. This same mechanism prevailed in 2000 when demand in satellite applications again did not increase and prices continued to fall.

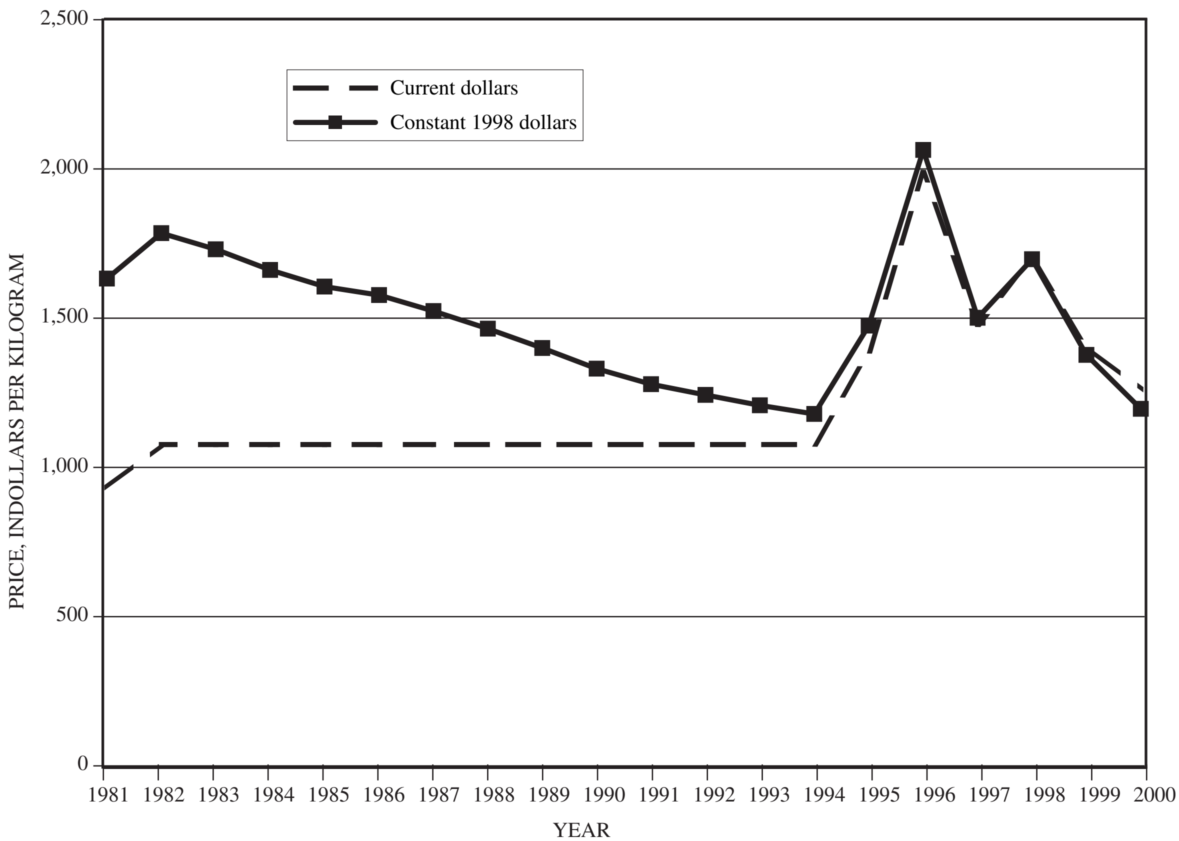

Figure 3. Annual average germanium metal price from 1981 through 2000. Values are shown in current and constant 1998 dollars per kilogram for zone-refined germanium metal at 99.9999% purity. Sources: Metals Week, 1980-93; Platt's Metals Week, 1993-94; U.S. Geological Survey, 1997-2002.

SOURCES OF GERMANIUM SCRAP

The value of germanium is a driving force for its recycling. Optical fibers and fiber optic detectors, which are the major end uses, accounted for about 50 percent of the end-use market in 2000. The amount of germanium recycled from finished fiber optic components (old scrap), however, is very small because this source has not yet been fully developed. New scrap materials reclaimed at manufacturing plants that produce germanium-containing fiber optic components are a major source of germanium supply and are delivered back to germanium processors for recycling. Germanium tetrachloride is used mostly in the manufacture of optical fibers and fiber optic detectors for the telecommunications industry.

Domestic fiber optic demand is dependent on the demand for improved telecommunications and the overall state of the high-technology portion of the U.S. economy. Optical fibers typically contain about 4 percent GeO_2 by weight (Lucent Technologies, 1997). The use of fiber optics also is affected by the perceived importance of increased speed, capacity, and clarity to the telecommunications industry consumers. This translates into a replacement of older copper-wire-based systems by fiber-optic-based systems by cable companies, network providers, and telephone companies (Freudenrich, 2003).

Another source of germanium scrap is broken lenses and glass from night vision devices, but only 5 to 10 percent of this material is recycled. Substrates, which are used mainly in solar cells, also are recycled especially where round substrates are manufactured. Generally, 20 to 25 percent of the substrates are unusable and will be recycled in manufacture as new scrap. Additionally, these round substrates are trimmed to squares, and an additional 25 to 30 percent is recycled, thus bringing the total new scrap recycled in substrate manufacturing to around 50 percent.

A small percentage of workable used computers and other electronic goods is sold and reused through the secondary resale market and is donated to schools and nonprofit organizations. Demanufacturing, or the disassembly of obsolete products, is another method for recycling electronic equipment, which often contains minute amounts of germanium. In North America, more than 300 facilities break down such electronic equipment components as hard drives and circuit boards for their resale value. Such barriers to demanufacturing as the lack of an adequate collection infrastructure, limited markets for recovered materials, and products that are not designed to be disassembled and recycled often make germanium recovery at these facilities unprofitable. Shredding is another option for recycling computer and other electronic equipment. Components, which range from laptops to mainframes, can be shredded, and the materials, separated, although the low germanium content precludes its economic recovery. Shredding is an efficient way to recycle large volumes of computers (Recycling Today, 2000; Resource Recycling, 2000a, b; Bleiwas and Kelly, 2001; Metal Bulletin Monthly, 2001; Mossholder, 2001).

DISPOSITION OF GERMANIUM SCRAP

In 2000, the 4.6 t of germanium recycled or reused from old scrap represented about 10 percent of domestic germanium supply. Because the United States has no germanium mining industry, germanium-bearing old scrap is a welcome addition to the germanium supply chain (See Infrastructure section). Of the estimated 9.2 t of germanium contained in old scrap that was available for recycling in 2000, about 25 percent was unrecovered, about 50 percent was used for domestic germanium supply, and the remainder was exported. Most of the unrecovered material was in the form of finished fiber optic cables. Recycling of germanium from old and/or discarded germanium-containing fiber optic systems has not been developed or used to any significant degree (ASM International, 1998).

RECYCLING EFFICIENCY

Recycling efficiency shows the relation between what is theoretically available for recycling and what was recovered and not recovered. This relation is defined as the sum of old scrap consumed plus old scrap exports divided by the sum of old scrap generated plus old scrap imports plus or minus old scrap stock changes, as applicable, and is expressed as a percentage. Most germanium is either recycled or reused in fiber optics in the form of soot material, off-specification preforms, and fibers, in night vision devices as broken lenses and glass, in plastic polymers as used food containers, and in semiconductor solar cells as trimmings from substrates. A germanium-recycling efficiency of about 76 percent was estimated to have been reached in 2000. The recycling efficiency would have been higher if a more concerted program to reuse germanium from its major end uses had been implemented (Thomas Shillinglaw, Corning Incorporated, oral commun., 2004).

INFRASTRUCTURE

Although germanium-containing ore was mined in Alaska and Tennessee in 2000, no germanium-containing ore was refined in the United States in 2000. All byproduct germanium was exported as concentrates. Metal, alloys, and compounds were produced by the Electro-Optic Materials Department of Eagle-Picher Industries, Inc. from reprocessed scrap, fly ash, germanium concentrates, and semirefined germanium materials. Cabot Corporation in Pennsylvania and Atomergic Chemetals Corporation in New York produced germanium from reprocessed scrap and semirefined imported materials.

Savage Resources Ltd.'s zinc refinery at Clarksville, Tenn., produced germanium-rich residues as a byproduct of the electrolytic refining of zinc during 2000. These residues were shipped to Union Minière SA's Electro-Optic Materials Business Unit in Belgium where a refined germanium product was produced.

The United States imports a significant amount of its germanium requirements. The U.S. International Trade Commission's Harmonized Tariff Schedule System (HTSS) categorizes some selected germanium materials as germanium oxides, waste and scrap, wrought metal, and unwrought metal. In 2000, imports of germanium metal and alloys totaled about 8.2 t of contained germanium valued at about $9.2 million. Overall imports came mostly from Belgium and China, but smaller amounts also came from, in descending order of quantity, Russia, Germany, Japan, Ukraine, Canada, Israel, the United Kingdom, the Netherlands, and France. Imports that were categorized as "waste and scrap" in the HTSS and as "old scrap imports" in figure 1 contained an estimated 0.5 t of germanium scrap; Canada and Russia were the major suppliers of this scrap. Unwrought germanium imports totaled 4.2 t, most of which came from China, and wrought germanium imports amounted to 3.5 t, most of which came from Belgium. The HTSS combines germanium oxides and zirconium dioxide in a single group, but a rough estimate of germanium oxide imports can be made based on the price of these imports.

Exports of germanium metal and alloys were insignificant, but a large portion of the overall production of finished goods, such as fiber optics and infrared devices, was exported. Old scrap exports exceeded old scrap imports by 1.9 t.

PROCESSING OF GERMANIUM-BEARING SCRAP

Recycling of germanium scrap is discussed under each end use topic below. In general, though, old and new scrap is sent back to the original plant to be remanufactured into new end forms. Many of the military night vision applications of germanium are sent to depots where they are separated into those to be reground or refinished by contractors and those that are too thin for another regrind. Those that are too thin are sent back to the original manufacturer for recovery and recycling.

Other old and new scrap from fiber optic applications, such as used or bad optical fiber, optical pieces, or ends, is sent back to the original manufacturer for reprocessing. The largest part of what can be considered new scrap is germanium chloride soot, which is captured in scrubbers and sent back to the original manufacturer for purification and reprocessing. Yield in production of fiber optic materials is estimated to be far less than 50 percent, and the balance of the material goes back to the manufacturer for reprocessing. New and old scrap from solar applications also is sent back to the manufacturer for reprocessing into final forms.

FIBER OPTICS

Although about 50 percent of the germanium consumed in the United States is used by the telecommunications sector, the amount of germanium recovered from obsolete fiber optic applications is small. The relative growth of the fiber optic telecommunications sector, the long life of fiber optic cables, and the lack of an improved substitute for fiber optic communication systems promote the continued use of germanium in fiber optic products.

The main reason for recycling most fiber optic scrap is to recover the contained germanium. There is value, however, in the recovery of other materials, such as soot material, off-specification preforms, and fibers. New optical fibers contain about 60 percent recycled material and 40 percent virgin material. Recovering of as much as 80 percent of the germanium in material sent back as scrap has been shown to be commercially feasible. Recycling has not been a major consideration since 2001 when fiber optic production slowed and the cost of recycled material was at or above that of virgin material (Dennis Thomas, Umicore USA Inc., oral commun., 2004).

A new process was developed in 1985 for the recovery of germanium from effluents generated in the production of optic fibers. A germanium filter cake was produced through a process that included a gas scrubbing unit and a recirculation unit followed by precipitation and filtration. This process was reported to recover greater than 95 percent of the unreacted germanium in the effluent stream (Roskill Information Services Ltd., 1990).

POLYETHYLENE TEREPHTHALATE CATALYST

The processing of germanium-containing PET is not particularly difficult or complicated, but the quality of the recycled product is degraded. PET resins are recycled in Japan, but the original bottles, which had contained potable liquids, are then remanufactured for use with products not to be consumed internally (for example, bleach and shampoo) and in other product containers for external-use-only materials.

Domestically, the trend has been moving away from the use of germanium as a catalyst in PET plastics. There is very little if any recovery of this material as old scrap. New scrap in internal production amounts to approximately 5 percent of the total used in new manufacture.

INFRARED OPTICS

As shown in figure 2, the use of germanium in infrared optical applications decreased drastically in the early 1990s. About 15 percent of the germanium that is consumed in the United States is in the infrared optics sector; the amount of germanium recovered from obsolete and broken night vision optical elements and other infrared optic devices is relatively small at between 5 and 10 percent of the contained germanium sold. The relative stability of the infrared optic market can be affected by new applications, such as the night vision systems provided on top-of-the-line cars, use in fire rescue and detection, and the use in military applications (Hindus, 2000; Truett, 2001).

OTHER USES

Germanium is used in manufacture of electrical and solar cells for use in satellite communication systems. This end use has been hard-hit in recent years by the delay of satellite launch projects. In this application, rounded substrates are cut into rectangular shapes to be used on the outside of satellites as part of the solar energy generation subsystem. Original manufacture of substrates has an approximately 75-percent yield rate with approximately 25 percent of the substrates recycled as unusable. An additional 25 to 30 percent of the germanium used in these substrates is recovered as new scrap when the rounded portions of the substrates are trimmed to form rectangular surfaces.

Additional applications for germanium include the production of phosphors for use in metallurgy and chemotherapy. Although it is still a relatively minor end use, several manufacturers have begun the production of silicon-germanium (SiGe) chips for use in telecommunications and computing equipment (Bindra, 2000; Paul, 2000).

GERMANIUM RECYCLING RESEARCH AND TECHNOLOGY NOTES

The Ontario Centre for Environmental Technology Advancement has reported a new process for the recovery of metals, including germanium that was developed by Met-Tech Systems Inc. This proprietary process is a liquid ion exchange that breaks down many metal complexes. The process begins by solubilizing the feed material or converting the material into a form that can be readily loaded onto an extractant. The metals can then be selectively loaded onto an organic phase. The aqueous and organic phases are separated by gravity in a settler. The individual metals are later stripped to high concentrations to produce a salable product. Once the metal has been stripped of the extractant, the organic phase is then recycled back to the metal extraction circuit for loading of additional metals (Ontario Centre for Environmental Technology Advancement, The, 1996).

Hydrometallurgical treatment of flue dusts from secondary smelters has yielded treatable residues that contain recoverable germanium. The process used by Hydrometal SA consists of repulping, leaching, purification, and cementation. Each of the processes after the leaching stage is followed by solid-liquid separation process. The final product is then a residue with recoverable germanium product (Goldschmidt, 1995).

OUTLOOK

The 20-year pattern of U.S. germanium consumption is shown in figure 2. The principal current use (almost 50 percent) for germanium, as $GeCl_4$ in the production of fiber optic components, mainly fiber optic cables, was expected to continue. This market sector was expected to be retarded by the slowing of growth in the telecommunications industry in the short run but was expected to continue steadily in the longer term. Development of germanium fiber optic recycling (old scrap) in the telecommunications sector, however, was very limited and represented a major potential for future germanium recycling. Germanium recycling in this area needed to wait for fiber optic systems to become obsolete and required technological change to become part of a total recycling concept for the telecommunications industry. This required time and major effort and cooperation between the germanium industry and future recyclers for the telecommunications industry.

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APPENDIX—DEFINITIONS

apparent consumption (AC). Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply (AS). AC plus consumption of new scrap (CNS).

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizers, making it exceptionally difficult and costly to recycle.

downgraded scrap. Scrap intended for use in making a metal product of lower value than the metal product from which the scrap was derived.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

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 borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities that consume old scrap. Included as new scrap is prompt industrial scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed in percent of new plus old scrap consumed; for example, 40:60.

old scrap. Scrap that includes, but not limited to, 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, used aluminum beverage cans, spent catalysts, and tool bits. This is also referred to as “postconsumer scrap” and may originate from industry or the general public. Expended or obsolete materials used dissipatively, such as paints and fertilizers, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as [consumption of old scrap (COS) plus exports of old scrap (OSE)] divided by [old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks], measured in weight and expressed as a percentage:

$$\frac{\text{COS + OSE}}{\text{OSG + OSI + decrease in OSS or - increase in OSS}} \times 100$$

old scrap supply. Old scrap generated (OSG) plus old scrap imported (OSI) plus old scrap stock (OSS) decrease:

$$\text{OSG + OSI + decrease in OSS}$$

old scrap unrecovered. Old scrap supply (OSSu) minus old scrap consumed (COS) minus old scrap exported (OSE) minus old scrap stock (OSS) increase:

$$\text{OSSu - COS - OSE - increase in OSS}$$

price. Unit value of contained germanium in materials used in calculating total value of contained metal in scrap.

recycling. Reclamation of a metal in usable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying metals (or base metals) in steel; recovery of antimony in battery lead; recovery of copper in copper sulfate; and even the recovery of a metal where it is not desired, but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and/or tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap, on an annual basis. It is defined as [consumption of old scrap (COS) plus consumption of new scrap (CNS)] divided by apparent supply (AS), measured in weight and expressed as a percentage:

$$\frac{\text{COS + CNS}}{\text{AS}} \times 100$$

scrap consumption. Scrap added to the production flow of a metal or metal product.