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Mineral Commodity Profiles

Antimony

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OVERVIEW

More than one-half of the primary antimony consumed in the United States goes into flame retardants. The remainder is used principally in glass for television picture tubes and computer monitors, in pigments, in stabilizers and catalysts for plastics, and in ammunition, cable covering, friction bearings, lead-acid (LA) batteries, and solders. It is used in the same applications worldwide, but its distribution among applications differs from country to country.

Antimony is mined in 15 countries, but mine production is concentrated very heavily in China (85 percent of the world total in 2000); most of the remainder is accounted for by South Africa (4 percent), Russia (4 percent), and Bolivia (2 percent). With the closing in 2001 of the sole domestic mine, in which it was produced as a byproduct of silver, antimony is no longer mined in the United States. In 2000, world mine production was about 118,000 metric tons (t). In addition to primary (newly mined) antimony, there is a substantial flow of secondary (recycled) metal, nearly all of which is reclaimed from and returned to use in LA batteries. In 2000, in the United States, secondary antimony accounted for about 15 percent of the domestic supply of antimony.

World resources are estimated to be from 4 million to 6 million metric tons (Mt) of contained antimony. The reserve base is estimated to be 3.2 Mt and reserves 2.1 Mt. China has nearly 60 percent of the world's reserve base; the United States has about 3 percent. U.S. resources are mainly in Alaska, Idaho, Montana, and Nevada.

HISTORICAL BACKGROUND

Archaeological and historical studies indicate that antimony and its mineral sulfides have been used by humans for at least 6 millennia. In ancient times, powdered stibnite, the most common mineral form of antimony sulfide, was, along with lead sulfide, a principal ingredient of kohl, the thick black paste used by the Egyptians and others as a cosmetic for coloring eyebrows and lining the eyes. The Chaldeans knew the art of winning the metal from its ores and casting it into ornamented vessels by 4000 B.C. It was being used as a plating on copper articles in Egypt by the middle of the third millennium B.C. The alchemist Basil Valentine is sometimes credited with "discovering" the element; in any case, he described the extraction of metallic antimony from its sulfide ore in his treatise "The Triumphal Chariot of Antimony," published sometime between A.D.1350 and 1600 (Li, 1953). Pliny the Elder named the metal stibium, and the eighth century Arabian alchemist Geber (Jabir) referred to it as "antimonium," from the Greek anti (against) and monos (alone), in allusion to its habit of existing in nature usually in compound form. Both names were used interchangeably for centuries (Li and others, 1992, p. 368).

When Gutenberg and others began using cast metal printing type in the mid-15th century, antimony was incorporated in it. By the middle of the 16th century, antimony was being used as the reflecting surface in mirrors and was being added to bell metal to impart a more pleasing tone to the cast bells, and its compounds were used in medication for ulcers and as yellow pigments for ceramics and glass (Li and others, 1992, p. 368).

As late as the 19th century, the number of uses for antimony and the amount used remained small. Most of it was used in type metal or alloyed with lead for use as bearing metal (babbitt metal) or with tin for use in Britannia metal as candlesticks, dinnerware, eating utensils, and so forth. After the lead-acid storage battery was developed at mid-century, lead battery plates hardened with antimony were noted to last longer in service than pure lead plates. A military use also appeared in the 19th century when a brittle lead alloy hardened with 10 to13 percent antimony was used for the spherical bullets contained in a new antipersonnel artillery shell invented by British General Henry Shrapnel. "Shrapnel" was used so extensively in the trench warfare of World War I that world antimony production between 1915 and 1918 averaged 53,000 metric tons per year (t/yr) and peaked at 82,000 t in 1916 these figures were not approached again until World War II (Schrader, 1921, p. 298).

After World War I, the burgeoning automobile industry, especially in the United States, created a strong and growing demand for LA storage batteries for which antimonial lead alloys were required. World demand for antimony plummeted during the early years of the Depression of the 1930s but recovered after a few years and then climbed sharply during the late 1930s as global conflict threatened again. Recovery of demand in the United States was somewhat more protracted. Antimony was again used in large quantities in World War II when world demand peaked at about 58,000 t/yr in 1942 and 1943 (Mote, 1948, p.128). With the abandonment of trench warfare in favor of maneuver and with an emphasis on mobile armored units, however, a much smaller fraction of military antimony went into fragmentation ammunition. Most of it was used in the LA batteries of military vehicles and in flame retardant compounds. The flame retardants were used primarily for heavy textiles, such as were made into tents and tarpaulins.

The basic list of wartime and peacetime uses of antimony has not changed much in the half-century since World War II, but the amounts used and the distribution among end uses have changed markedly. The very rapid growth in the use of plastics as structural and packaging materials has created the dominant market for antimony—flame retardants, which are used largely for plastics. In the last quarter century, changes in the design of LA batteries have cut the use of antimony in battery alloys markedly despite the ever-growing market for batteries. These and other developments are discussed in the section "Uses."

World mine production of antimony in the 20th century was dominated by a handful of countries. In the first two decades, China and Bolivia produced much of the antimony. Then Mexico in the 1920s and South Africa and the U.S.S.R. in the 1950s joined them as important producers. In the 1980s and early 1990s, China increased production very rapidly, until by 1999, it accounted for more than 80 percent of the world's mine production of antimony (fig. 1).
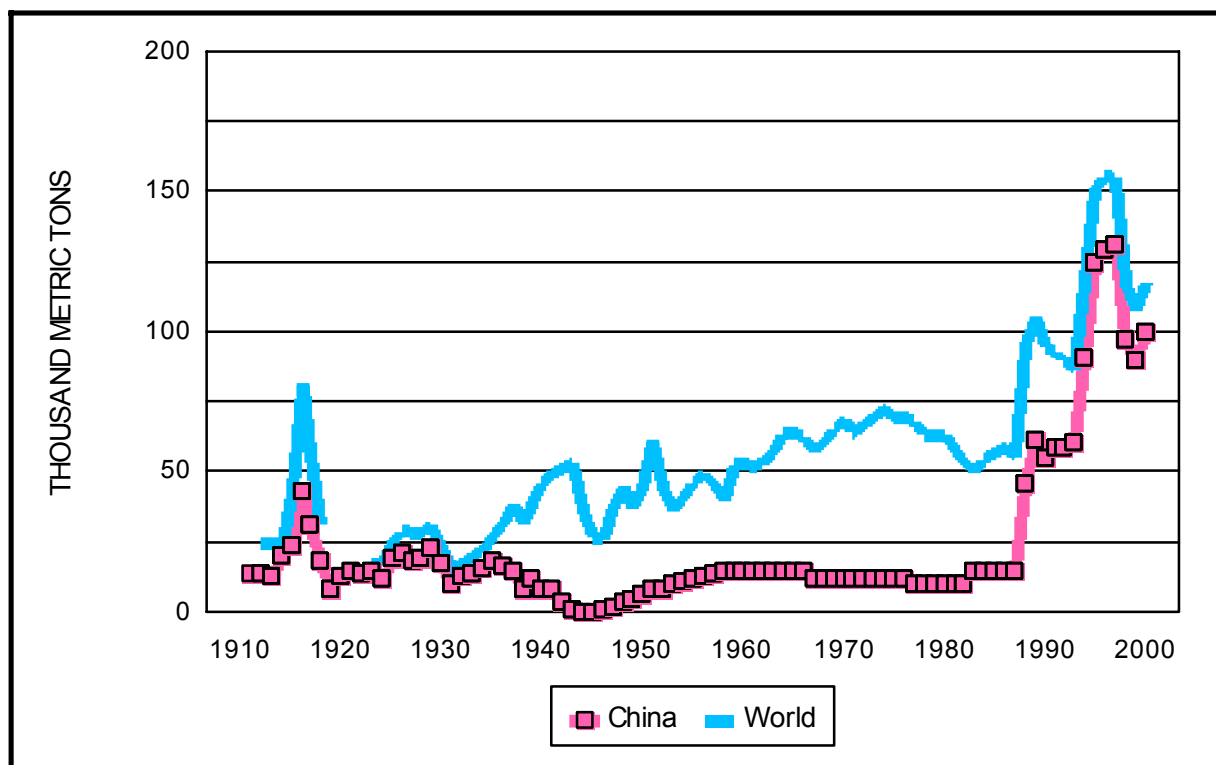
Figure 1: Antimony mine production, 1911-2000. [Data from U.S Bureau of Mines, 1924-31, 1932-95; U.S. Geological Survey, 1910-1923, 1996-2001]

Through most of the 20th century, the United States was a small- to medium-sized producer of mined antimony. Domestic production of antimony as a principal mine product (that is, from antimony ores) was as high as 5,000 t in 1943; in 1948, it peaked at about 5,900 t. Most of the production in those years came from the Yellow Pine Mine, in Idaho. After the early 1950s, production as a principal product dropped well below 1,000 metric tons per year (t/yr). From the 1940s through most of the 1950s, domestic byproduct production, which was mostly from lead ores, ranged between 1,000 and 2,000 t/yr; thereafter, it remained below 1,000 t/yr in most years (Miller, 1973). After the mid-1980s, byproduct production was not reported by domestic lead mining companies. At the end of the century, a few hundred tons per year was being produced as a byproduct of silver mining at the Sunshine Mine, in Idaho, but in early 2001, the mine was closed and place on care and maintenance status.

DESCRIPTION

SALIENT FACTS

Antimony (atomic number 51 and atomic weight 121.75) is located in period 5, group 11 (or VA), of the periodic table of the elements and is, in appearance, a lustrous tin-white metal. Although it is usually described as a metal, it possesses mixed metallic and nonmetallic characteristics, and is more properly described as a semimetal or metalloid. Unlike typical metals, it is not malleable, but hard and brittle and can be crushed to a powder. Compared with metals, antimony is a poor conductor of electricity and heat. Along with the other semimetals (silicon, germanium, arsenic, and tellurium), it is positioned in the periodic table along the boundary between the metals and the nonmetals. Its common oxidation states are +5, +3, 0, and –3, although other oxidation states have been recognized. Natural antimony consists of a mixture of two stable isotopes that have atomic weights 121 (57.25 percent by weight) and 123 (42.75 percent by weight); in addition, about three dozen radioactive isotopes are known. Antimony's average concentration in the Earth's crust is 0.20 gram per metric ton (g/t). Antimony metal melts at 630.6 $^{\circ}$C, has a specific gravity that ranges from 6.62 to 6.69 depending on the method of preparation of the metal, and a hardness of 3 to 3.5 on the Mohs scale and about 55 on the Brinell scale. Antimony crystallizes in the rhombohedral class of the hexagonal system (Li and others, 1992; Anderson, 2001).

PRINCIPAL FORMS, ALLOYS, AND COMPOUNDS

"Crude antimony" and "crudum" are terms applied to ore that contains more than 90 percent antimony, and to liquated sulfide ore, which is essentially an antimony-sulfide mixture that contains 70 percent or more antimony (Wyche, 1976). Refined antimony metal, or regulus, is the stable common form (allotrope) of antimony. Three other allotropic forms are sometimes described—black (or gray), yellow, and explosive. Black antimony is an amorphous metal formed by the rapid quenching of antimony vapor. Yellow antimony is formed by the low-temperature oxidation of stibine (SbH_3); it is thought to be an impure material and probably is not a true allotrope of antimony. Explosive antimony is described as an ill-defined material that is thought to be in a strained amorphous state. It, too, is probably not a true allotrope of antimony (Li and others, 1992).

Because of its hardness, brittleness, and lack of malleability, antimony has no commercial uses as a metal by itself except for small amounts used for ornamental castings and semiconductor devices. Instead, it is a minor component in many lead- and tin-based alloys to which it lends strength and hardness. The most quantitatively important alloys of antimony are lead based and are commonly formulated by adjustment of the composition of the lead refinery product called antimonial lead; the latter may contain up to 25 percent antimony, but more commonly contains single-digit percentages. Most of the antimony that is used in the metallic state, as in LA batteries, cable covering, and several other applications, is used as some form of antimonial lead. Antimony is also a component of several tin-based alloys, such as britannia metal, pewter, white bearing metal (true babbitt), and a new alloy, a tin-antimony-silver solder used for joining pipes for carrying potable water. The compositions of the principal antimony alloys are shown in table 2.

Antimony forms a very large number of inorganic and metallo-organic compounds. The sulfides predominate in nature and are available to commerce as processed antimony ores. In terms of the quantities produced, the most important synthetic antimony compound by far is the trioxide (Sb_2O_3), which is used by itself for some uses and as the chemical intermediate from which a great many other antimony compounds are made. Other prepared compounds used in substantial quantities are the pentoxide (Sb_2O_5), sodium antimonate ($NaSbO_3$), the trisulfide (Sb_2S_3), the pentasulfide (Sb_2S_5), and the triacetate $Sb(CH_3COO)_3$. These compounds are used variously as flame retardants, pigments, heat and radiation stabilizers for plastics, and catalyst precursors.

COMMERCIAL FORMS, GRADES, SHAPES, AND SPECIFICATIONS

Antimony sulfide ore is marketed in at least three forms for which prices are published— lump sulfide ore (minimum 60 percent contained antimony), clean sulfide concentrate (minimum 60 percent contained antimony), and Chinese concentrate (minimum 60 percent antimony, maximum 30 parts per million (ppm) mercury, and typically 60 ppm selenium).

The principal commercial form of processed antimony is the trioxide, which is used primarily in flame retardants, heat/UV stabilizers for polyvinyl chloride (PVC) and other plastics, and as a catalyst precursor for the manufacture of polyethylene terephthalate (PET) plastics. The trisulfide is sold for use as a pigment, and the

pentasulfide, for use as a rubber vulcanizing agent. The triacetate is a catalyst precursor used in PET manufacture. Refined metal is also an important item of commerce but, especially in the United States, is used mostly as an intermediate form from which trioxide is made. Finally, antimonial lead scrap from discarded LA batteries is an important commercial source for re-use as antimonial lead alloys.

Antimony metal (regulus) is usually sold in 10- by10- by 2 ½-inch pieces that weigh about 60 pounds, and are referred to variously as "blocks," "bars," or "pigs." It is also available as semicircular broken pieces, cast cake, granules, ingots, powder, shot, and single crystals. Commercial metal is at least 99 percent antimony with no more than 0.3 percent arsenic as an impurity (Wang, 1952, p. 140). The largest amount on the market is Chinese No. 2 grade, which has minimum 99.65 percent antimony. In the United States, American Society for Testing and Materials (ASTM) specifications have been established for two grades, A and B, as follows (Plunkert, 1985):

Grade A metal	Mininum antimony 99.8 percent. Maximums–arsenic, 0.05 percent; sulfur, 0.10 percent; lead, 0.15 percent; and other elements, 0.05 percent each.
Grade B metal	Minimum antimony 99.5 percent. Maximums–arsenic, 0.1 percent; sulfur, 0.1 percent; lead, 0.2 percent; and other elements, 0.1 percent each.

Antimony metal prepared for semiconductor use in electronics is 99.999 plus pure.

Commercial grades of antimony trioxide contain 99.2 to 99.8 percent trioxide with iron, lead, and arsenic as the main impurities. Several grades that provide different tinting strengths when used as pigments are available. For example, one domestic company (Essen Corporation) markets three oxides that differ in tint strength, which is an inverse function of particle size, as follows:

"Alpha-grade" oxides	Average particle size, in micrometers	Tint strength
No. 1	0.2-0.6	very high
No. 2	0.8-1.5	high
No. 3	2.5-3.5	low

SOURCES OF ANTIMONY

PRIMARY ANTIMONY

Among the elements found in the earth's crust, antimony ranks 63d in abundance. At an average concentration of 0.20 g/t, it is less abundant than tin, arsenic, or the rare earths but more abundant than bismuth, mercury, or silver. Its abundance in igneous rocks ranges from 0.1 to1 g/t, and in sedimentary rocks is "very small," and the amount in seawater is about 0.0002 g/t (Lide, 1999, p. 14-14). Antimony tends to concentrate in sulfide ores along with copper, lead, and silver. It occurs sparingly as the free metal, usually in association with arsenic, bismuth, or silver. The most important ore minerals of antimony are the sulfides stibnite and jamesonite; they are followed by the oxides senarmontite and valentinite, then in less certain order by the other five minerals listed in table 1, and by others of lesser importance that are not listed.

Table 1. The principal antimony ore minerals.

Name	Composition
Stibnite	Sb_2S_3
Jamesonite	$Pb_2Sb_2S_5$
Senarmontite, Valentinite	Sb_2O_3
Stibiconite	$H_2Sb_2O_5$
Bindheimite	$Pb_2Sb_2O_7.nH_2O$
Kermesite	Sb_2S_2O
Tetrahedrite	$Cu_8Sb_2S_7$

Antimony deposits are believed to have formed from hydrothermal solutions at low temperature and shallow depth and typically occur as epithermal fissure or joint fillings, pegmatites, replacement lodes, or hot-spring deposits. The deposits tend not to be concentrated in rocks of any particular geologic age or type. Following White (1951, p. 3), they are divided for discussion here into two general types, termed simple and complex. Simple deposits tend to be simple both in structure and mineralogy. They consist predominately of antimony minerals with small to negligible quantities of other metallic minerals. The ore mineral is almost always the sulfide, stibnite, although native antimony is occasionally present. The stibnite commonly has been oxidized wholly or in parts of the deposit to the antimony oxide minerals. Some of the world's largest sources of antimony are of this type and are found in China, South Africa, the Confederation of Independent States (CIS), and Bolivia among current important producing countries. Complex deposits hold mixtures of antimony-bearing sulfides and sulfosalts of iron, copper, lead, mercury, or silver. These deposits are nearly always mined for one or more of the other metals, but antimony can be a valuable byproduct. Antimony mined in China, Australia, Canada, and the United States tends to come from complex deposits (Miller, 1973; G.C. Tejada, October, 2002, Essen Corporation, written comm.). The Sunshine Mine extracted it from a complex silver-copper-antimony sulfide ore (U.S. Geological Survey, 2001, p. 7.1-7.8). A small amount of antimony may be recovered in primary antimonial lead at U.S. lead producers, but the quantity, if any, is no longer reported.

RESERVES, RESERVE BASE, AND RESOURCES

Reserves and reserve base for several of the leading antimony-producing countries are shown in table 2. These include antimony contained in ores where antimony is the principal value and antimony contained in base and precious metal ores where it is a subordinate value.

Table 2. Antimony reserves and reserve base, yearend 2000.
[In metric tons. All data are rounded to two significant digits; because of independent rounding, they may not add to totals shown. Carlin, 2001, p.21. See Appendix for definitions of terms]

Country	Reserves	Reserve base
United States	80,000	90,000
Bolivia	310,000	320,000
China	900,000	1,900,000
Kyrgyzstan	120,000	150,000
Russia	350,000	370,000
South Africa	240,000	250,000
Tajikistan	50,000	60,000
Other countries	25,000	75,000
World totals	2,100,000	3,200,000

Identified world resources of antimony, which probably are in the range of 4 to 6 Mt, are in Bolivia, China, Mexico, Russia, and South Africa. U.S. resources were estimated in the early 1970s to total at least 100,000 t, about one-fourth of which was in the Yellow Pine district in Idaho, where little antimony was being produced, another one-fourth was in scattered simple-type deposits that were uneconomic to mine at the prevailing antimony prices, and one-half was in complex deposits with silver and base-metal ores from which the antimony was recovered as a byproduct (Miller, 1973).

At the level of mine production in 2000, the world reserves listed in table 2 could be used up in about 18 years; the reserve base in 27 years; and all identified resources, assuming they could be produced economically, in roughly 35 to 50 years. Exhaustion of reserves and resources in those relatively short spans of time is unlikely, however, because reserves tend to be replaced as they are mined, and exploration is likely to discover new deposits, some of which will be economical to mine.

SECONDARY ANTIMONY

Antimony recovered from scrap is an important part of the total antimony supply but one that has declined greatly in importance in the last quarter century. Since the 1920s, the largest source of secondary antimony by far has been scrapped LA batteries, mostly automotive vehicle batteries. Other sources have been bearing metal, cable coverings, solder, and type metal, nearly all of which are lead-based alloys. Being lead-based, most antimony scrap is reprocessed at lead smelters into reconstituted antimonial lead, nearly all of which returns for use in LA batteries. Because of the limited life of LA batteries and the huge stock of them in use, the component of scrap derived from old (postconsumer) scrap has long been much more important than that derived from new (manufacturing) scrap (fig. 2). With the advent in the 1970s of low-maintenance and maintenance-free automotive batteries, which use little or no antimony, the supply of antimony-containing scrap has gradually diminished. U.S. smelter production of secondary antimony, which was on the order of 20,000 t/yr in the 1950s and 1960s, had dropped to about 8,000 t/yr by 1999 and may drop farther (fig. 3). In 1999, secondary antimony, almost all of it derived from used LA batteries, accounted for about 15 percent of the total U.S. market supply of antimony.
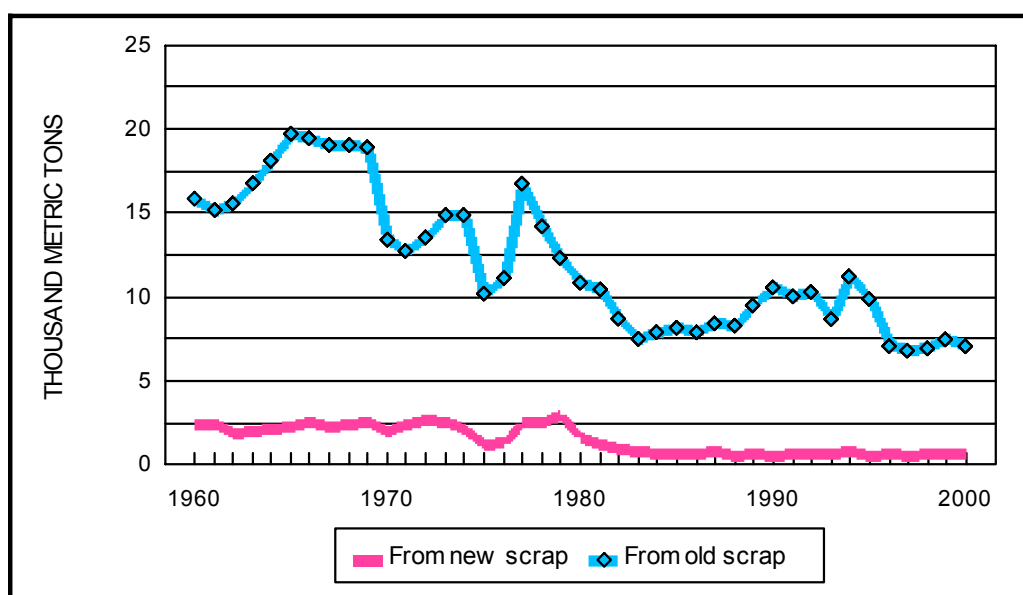

Figure 2: U.S production of secondary antimony, by type of scrap. [Data from U.S. Bureau of Mines 1960-95; U.S. Geological Survey, 1996-2001]
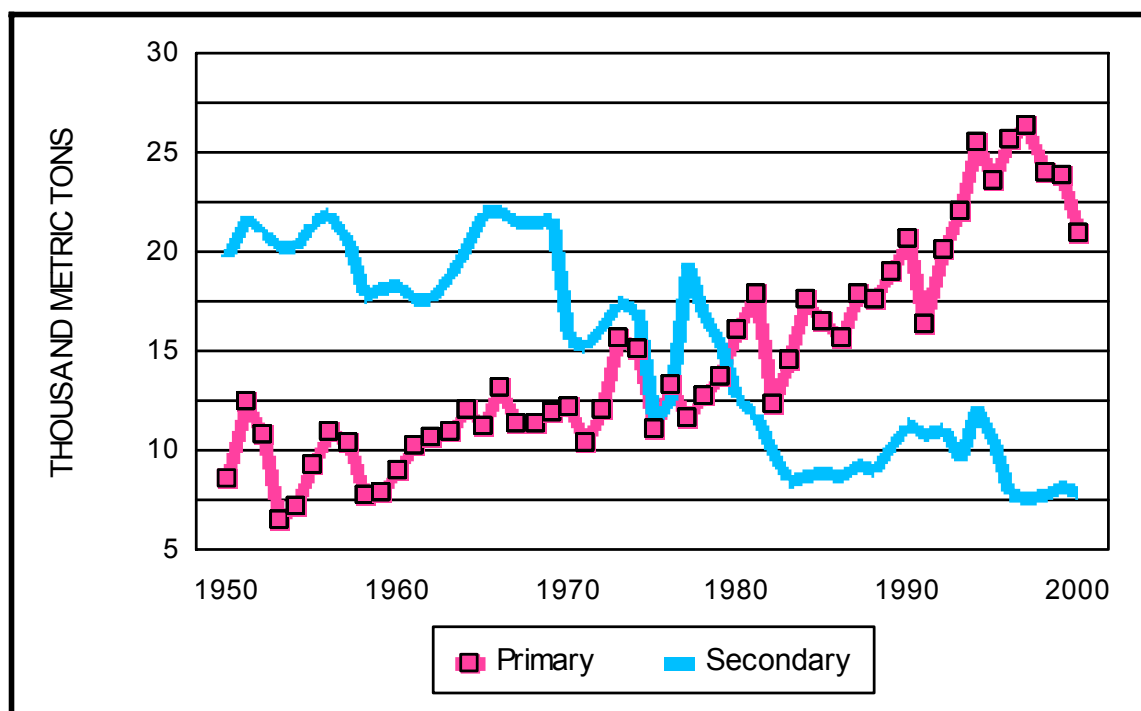
Figure 3: U.S. smelter production of antimony. [Data modified from U.S. Bureau of Mines 1950-95; U.S. Geological Survey, 1996-2001]

PRODUCTION TECHNOLOGIES

MINING

The typically small ore bodies in mines from which antimony is produced as a principal product do not lend themselves to exploitation on a large scale. When possible, they are mined by open pit methods. Underground antimony mines typically are small, the ore body being accessed by a short adit or shaft, and are developed by drifting along the vein and stoping by simple overhand methods. Mines in which antimony is produced as a byproduct use the large-scale methods common to base- and precious-metal mines (Plunkert, 1985).

PROCESSING

At least six principal methods are or have been used to extract antimony from its ores. The method used depends on whether the ore is a sulfide, an oxide, or a complex ore, and on the grade, which ranges widely from about 1.5 percent to more than 60 percent antimony by weight.

Of the sulfide ores or concentrates thereof made by the froth flotation process, those that contain from 1.5 to 25 percent antimony are roasted to produce oxides, and those with from 25 to 45 percent antimony are smelted in blast furnaces to produce crude metal. Those ores with from 45 to 60 percent antimony are liquated; that is, heated in a reducing atmosphere to melt the antimony sulfide, which is poured off from the gangue and when solidified upon cooling is referred to variously as "crude antimony," or "crudum," or "needle antimony." Instead of being liquated, the richest sulfide ores have sometimes been treated by the precipitation process, in which antimony is displaced chemically from the molten sulfide by iron shavings and yields impure antimony metal.

Oxide ores that contain on the order of 30 percent antimony are reduced in blast furnaces to crude metal; richer ores, which contain on the order of 50 percent antimony, are reduced and refined to commercial-grade metal in reverberatory furnaces.

Mixed sulfide and oxide ores are usually smelted in blast furnaces. Complex antimony-bearing ores are sometimes processed by selective leaching followed by electrolysis of the leachate to recover the metal (Wang, 1952, p. 38-121; Plunkert, 1985; Li and others, 1992).

VOLATILIZATION ROASTING

In volatilization roasting, the sulfide ore or concentrate is mixed with charcoal or coke and heated in one of various kinds of roasters or shaft furnaces. The volatilized antimony oxides are recovered in some combination of bag houses, condenser pipes, flues, or precipitators. The sulfur leaves as the gaseous dioxide and is recovered from the waste gases. Control of the roasting temperature and the amount of oxygen made available determine the type of oxide produced. Most of the oxide produced by volatilization is impure but suitable for reduction to metal or upgrading as trioxide. Marketable trioxide, however, can be produced by close control of roasting conditions. Thus, volatilization is sometimes used as an intermediate ore beneficiation step and sometimes as an extracting/refining process that yields a marketable oxide. If the roasting is carried out in the presence of excess oxygen (dead roasting) then the product is the tetroxide (Sb_2O_4), which has no market value except as a precursor of antimony metal. Dead roasting is seldom used.

BLAST FURNACE SMELTING

In modern practice, the intermediate grades of antimony ore of all kinds are smelted in a blast furnace. This is the most important process for the extraction of antimony from its ores. The furnace feed can consist of briquetted fines or flue dust, mattes, mixed ores, oxides, sulfides, and residues and slags,. The large amount of slag formed is beneficial in reducing volatilization losses of the metal. The product is impure antimony metal.

LIQUATION

In this process, the higher-grade sulfide ores are heated in reverberatory furnaces or crucible furnaces in a reducing atmosphere at from 550 to 600 ^{o}C, temperatures below the volatilization temperature of the stibnite but above its melting point. The molten sulfide trickles down through the ore mass and is collected at a lower level of the furnace. The solidified sulfide, which is more than 70 percent antimony, is usable for some purposes as is, or it may be converted to metal or oxide.

REDUCTION

The highest grade oxide ores are reduced to metal in reverberatory or short rotary furnaces by charcoal. An alkaline slag cover minimizes volatilization losses and simultaneously removes impurities from the molten metal. The first product is crude antimony metal, which may be refined to 99 percent plus purity by further treatment in reverberatory furnaces.

LEACHING/ELECTROWINNING

Antimony is recovered from some complex ores by leaching, followed by electrowinning. A typical process uses sodium sulfide or sodium hydroxide as the solvent. The filtered leach solution, which contains sodium thioantimonate (Na_3SbS_4) is electrolyzed in a diaphragm cell fitted with mild steel electrodes. The cathode metal recovered is 93 to 99.5 percent antimony depending on ore feed and process parameters.

PRECIPITATION

Antimony can be extracted from sulfide ore concentrates, rich sulfide ore, or liquated sulfide by chemical displacement in the molten state by iron. The process (originally referred to as the "English process") is usually carried out in crucible furnaces with fine iron or steel scrap or steel turnings, shavings, or cuttings in an amount slightly in excess of the stoichiometric requirement. An iron sulfide matte floats on the surface of the molten antimony metal. The product is an impure metal that is contaminated with iron and sulfur.

Commercial-grade and high-grade antimony oxides (the latter for use in applications such as flame retardants and pigments, where particle size and shape must be controlled closely) are made by revolatilization of impure oxide or by the volatilization of refined antimony metal.

The antimony metal produced by the primary processes outlined above normally must be refined to attain commercial purity. The principal impurities are usually, in declining order of abundance, lead, arsenic, sulfur, iron, and copper,. Iron and copper levels may be lowered by heating the metal with stibnite or a mixture of sodium sulfate and charcoal to form a molten ferriferous matte, which is then skimmed from the surface of the metal. The molten metal is then covered with an oxidizing flux of caustic soda or sodium carbonate and niter (sodium nitrate) to remove the arsenic and sulfur. The lead cannot be readily removed from antimony metal, but antimony that contains lead as a contaminant finds ready use in the production of antimonial lead and lead-based alloys.

RECYCLING

Antimonial lead, which has many uses, can be produced from lead ores but it is essentially a secondary metal product, especially in the United States. Most of it is produced at secondary lead smelters from scrap battery grids and other battery parts and from bearing metal, type metal, and other antimonial lead scrap. There, the blast furnace smelting step yields lead bullion, which is then refined in pots or reverberatory furnaces where lead or antimony is added as required to bring the alloy to specification (Plunkert, 1985).

USES

Nearly all antimony is consumed in one of the following four forms: antimony trioxide, which is used mostly for flame retardants; antimonial lead alloys, which is used mostly in batteries but also in other products; refined antimony metal, which is used in LA batteries and a variety of metallic products; and sodium antimonate, which is used for the clarification of specialty glasses.

This discussion of antimony use deals largely with the use of primary (newly mined) antimony owing to the dearth of information on the consumption and production of secondary antimony in most countries. The United States publishes figures on the production, but not on the consumption, of the secondary metal. Because antimonial scrap reportedly is processed only as needed, these production figures may be used with little error as consumption figures. Nearly all secondary antimony is recovered from and returns to use as antimonial lead alloys. More specifically, most of it arises from spent LA batteries, and much of the recycled metal returns to use in batteries.

Primary antimony accounts for only about one-fifth of the antimony used in batteries but for larger proportions in most other metallic products and usually accounts for all the antimony used in nonmetallic products. The statistical situation for this primary antimony is somewhat clearer than for secondary antimony. Only France, Japan, the United Kingdom and the United States publish data on consumption; the apparent consumption of most countries, however, can be derived as the sum of domestic mine production and the import/export balance, providing imports exceed exports. Apparent consumption is an approximation, because data on industrial and Governmental stock changes are usually unavailable. World consumption of primary antimony is probably on the order of 100,000 t/yr, with the United States accounting for about one-half and Europe one-third of the total (Roskill Information Services, Ltd., 2001, p. 121).

The use patterns for primary antimony in the United States and the world are shown in figures 4 and 5. In North America, Western Europe, and Japan, flame retardants account for more than one-half of the primary antimony consumed. As recently as 1995 in the CIS, however, batteries and antimony alloys accounted for more than two-thirds of the primary antimony used (Roskill Information Services Ltd., 1997, p. 94). The metallic uses, which had been dominant, have declined in importance in the United States since the early 1970s; in 1999, they accounted for only about 10 percent of the primary antimony consumed.

(57.4%)   Flame retardants

(10.4%)   Other uses

(4.1%)   Lead-acid batteries

(9.6%)   Plastics stabilizers and catalysts

(8.9%)   Pigments

(9.6%)   Ceramics and glass

U.S. total 39,400 metric tons
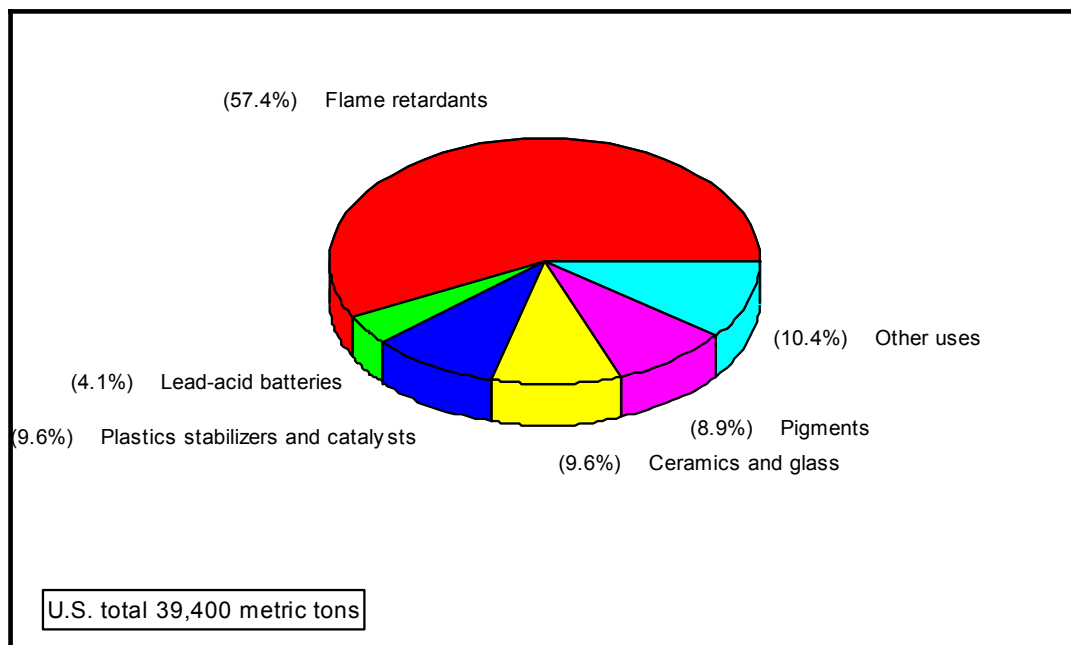
Figure 4. Estimated U.S. consumption of primary antimony in 1999**.**
[Based partly on data from U.S. Geological Survey, 2000]

(60.0%) Flame retardants

(20.0%) Other uses

(20.0%) Batteries & alloys
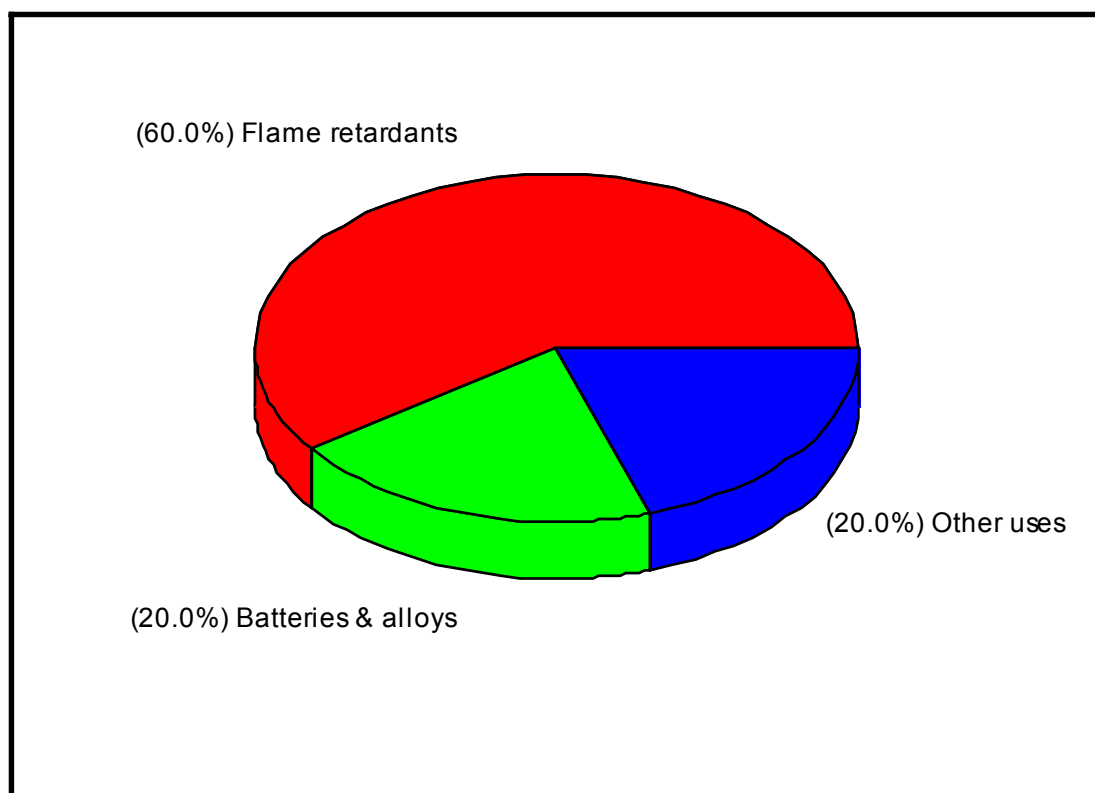
Figure 5. World consumption of primary antimony in 2000.
[Roskill Information Services Ltd., 2001, p. 122]

If, in the absence of world consumption data for primary antimony, world mine production is used as a proxy, it can be seen that consumption grew slowly, averaging about 1.9 percent per year over nearly two-thirds of the century, from the early 1920s through 1987, (fig. 1). In the United States, apparent consumption of primary antimony declined sharply in the post-World War II years but began to grow again in the 1950s; for the next 30 years, it grew at an average rate of about 1.4 percent per year. From 1983 through 2000, it grew much faster, at about 5.6 percent per year (fig. 6).
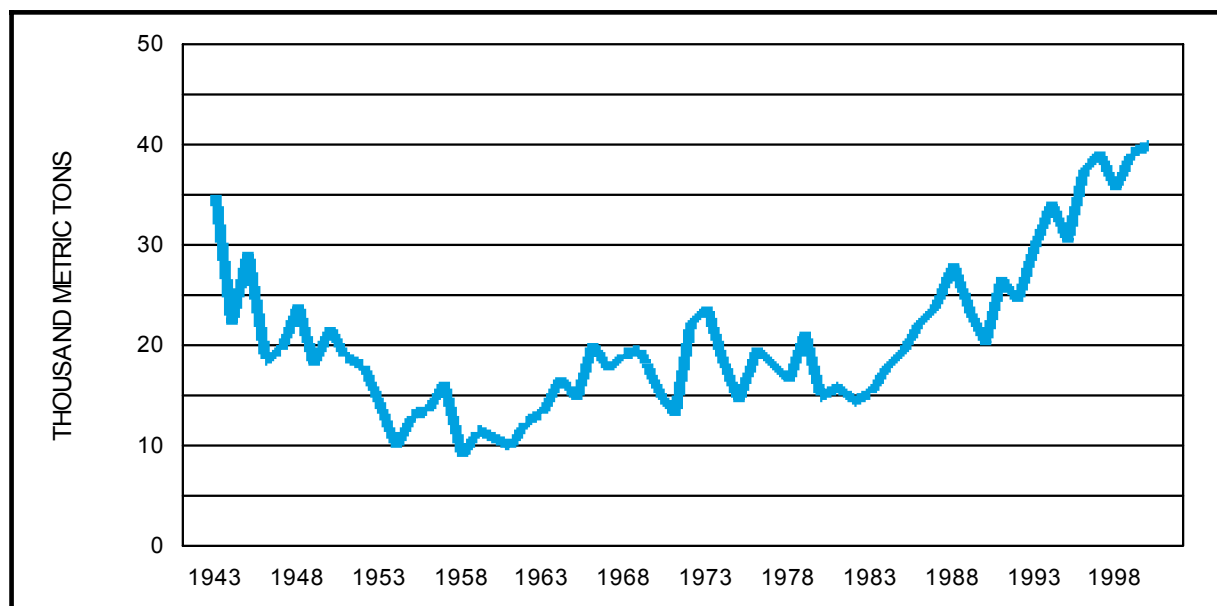
Figure 6: U.S. apparent consumption of primary antimony, 1943-2000. [Calculated from data in U.S. Bureau of Mines 1943-95; U.S. Geological Survey, 1996-2001]

METALLIC USES

Antimony itself is hard and brittle and is used alone only for very minor uses, such as ornamental castings. But its compatibility with lead and other low-melting-point metals make it useful in alloys. As an alloying agent, antimony hardens and strengthens lead and its alloys. Metallic antimony expands upon solidification, making it a valuable component of precision-cast alloys, such as type metal. The compositions of the principal antimony alloys and the applications for most of them are shown in table 3, and the consumption pattern for all metallic uses of antimony in the United States in 1999 is shown in figure 7.

(39.3%) Batteries

(2.5%) Bearings

(4.9%) Solder

(53.3%) Other uses

Estimated total 4,070 metric tons
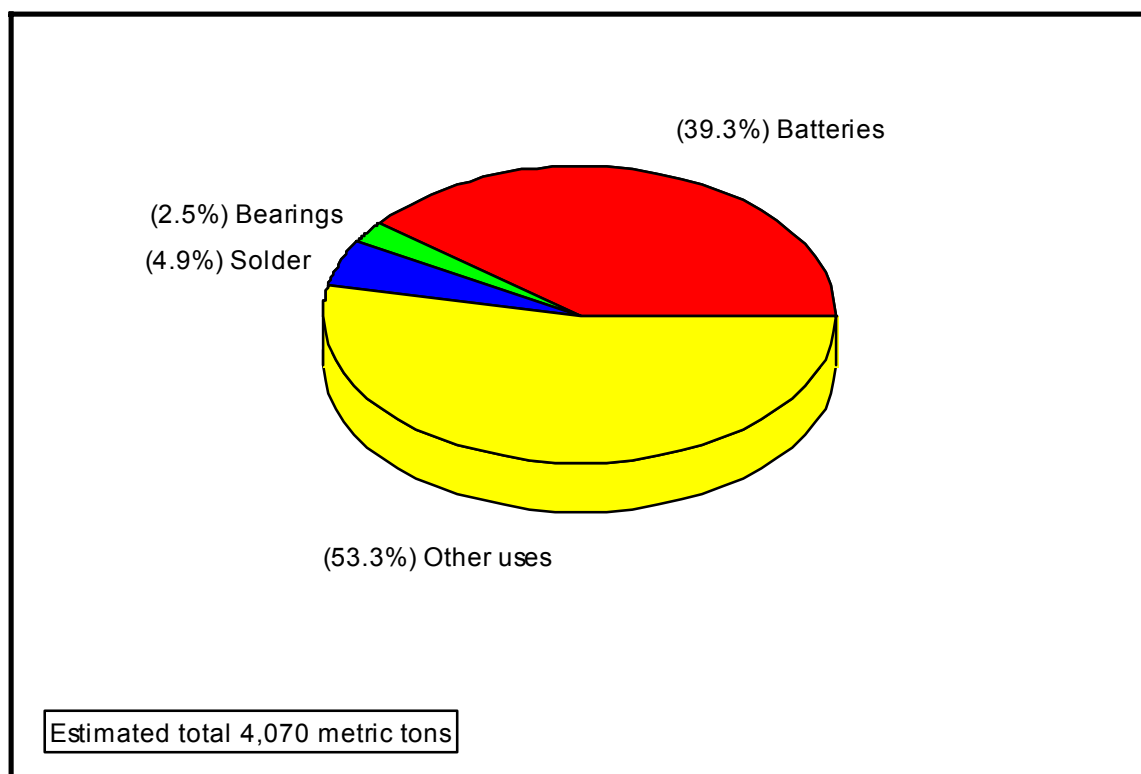
Figure 7: Estimated U.S. consumption of primary antimony for metallic products in 1999. [Based on data from U.S. Geological Survey, 2000]

Table 3. The principal antimonial alloys, by application.
[Contents in weight percent. [Various sources]

Alloy	Antimony	Tin	Lead	Other metals
Battery grids	1.6	0.2	balance	0.2
Bearing metal (lead babbitt)	9 - 16	0- 12	do.	0.5 - 1.5
Bearing metal (true babbitt)	6 - 8	balance		3 - 8
Britannia metal	2 -10	do.	0- 9	1.8 - 10
Chemical Industry sheet, pipe	4 -15	0.25-1.0	balance	
Chemical Industry pumps, valves	12	0.25-1.0	do.	
Bullets	0.5 - 1.5		do.	
Collapsible tubes	1-4		do.	
Electrical cable covering	0.5 -1.0	0.25-1.0	do.	
Fragmentation ammunition	12 - 15	0.25-1.0	do.	
Pewter	1 - 8	balance	0-0.05	0 - 2
Roofing and gutters	6		balance	
Sheet and pipe	2 - 6	0.25-1.0	do.	

Solder: autobody solder (filler)	2-5	2-5	do.	
Solder: plumbers solder	0 - 2	38 – 42	balance	
Solder: soft	<0.5	60-63	37-40	
Specialty castings	11	1	do.	0-0.5
Type metal	4 - 23	3 - 17	do.	0.5 - 2

LEAD-ACID BATTERIES

Since the LA battery was developed in mid-19th century, it has been by far the most important secondary (or rechargeable) battery in use worldwide. LA batteries may be categorized either as starting, lighting, and ignition (SLI) batteries, which are used in motor vehicles, or as industrial batteries. Industrial batteries include traction batteries, which are used in forklifts, mine locomotives, golf carts, and so forth; stationary batteries, which are used as telephone exchange batteries, emergency power batteries, load-leveling batteries, and so forth; and miscellaneous other types. In the United States, more than 90 percent of LA batteries manufactured in recent years have been of the SLI type, while about 5 percent have been traction types and 5 percent stationary types. Within a few years of the development of the LA battery, manufacturers began alloying lead with antimony for certain parts of the battery for which good strength, corrosion resistance, and creep resistance were needed. The largest of these parts is the plate grid, the inactive part of the battery plate that gives mechanical support to the active electrode materials (spongy lead dioxide in the positive plate and sponge lead in the negative plate) and provides a conductive path for the electric current. In addition to strengthening the lead, antimony simplifies and speeds up the casting of grids by enhancing the fluidity of the
melt and minimizing shrinkage during cooling. After the battery goes into service, antimony leached slowly from the grid promotes recrystallization of the lead oxide active material, which keeps the material firm and retards the progressive softening and spalling that can otherwise develop with service age.

Antimony has at least two disadvantages. Antimony tends to migrate during discharge from the positive to the negative plate where it lowers the hydrogen overvoltage, augmenting the breakdown of water in the electrolyte and the evolution of hydrogen; this requires venting of the battery case, and the consequent loss of water from the electrolyte necessitates battery "maintenance" (periodic addition of water to the electrolyte). And as it deposits on the negative plate, antimony sets up local cells; these cause self-discharge of the battery at rates of up to 1 percent per day of battery charge when the battery is standing idle.

To lessen the need for maintenance, manufacturers of SLI batteries began more than 30 years ago to decrease the amount of antimony used in plate grids, developing first "low-maintenance" batteries and eventually "maintenance-free" batteries. The changeover was driven not only by convenience to the automobile owner, but by the much higher under-hood temperatures typical of modern automobiles, which increased the corrosion rate of the positive grid, and by the trend towards a much larger electrical load, which required a larger number of plates in each cell. Because the outer dimensions of the battery were not allowed to increase, using more plates meant using thinner plates, which necessitated a change in the method of manufacture of the grids. The result is that calcium-lead, which has better electrical conductivity and lends itself to rapid automated casting of grids, has largely replaced antimonial lead in grids in Europe and the United States where the modern automotive battery is a sealed unit that requires no maintenance during its lifetime (Rand and others, 1998, p. 166-170). Its use in plate grids in some batteries accounts for nearly all the antimonial lead still used in batteries, but a 3 percent antimony alloy is still used for the posts and cell connectors of virtually all types of LA batteries, including maintenance-free automotive types (Prengaman, 1995, p. 116). The change in antimony consumption in LA batteries in the United States may be seen in table 6.

Substantial tonnages of antimony are still being used in some countries in automotive batteries and in all countries in stationary batteries. A representative number for the antimony content of grids in U.S. automotive batteries 35 or 40 years ago would have been about 7 percent by weight. In the few conventional batteries with antimonial lead grids still being manufactured in the United States today, the antimony content of grid alloys is about 1.6 percent (Siegmund and Prengaman, 2001). In the mid-1990's, antimony was still being used extensively in plate grids of automotive batteries in Asia and in the countries of the CIS, where its content in grid alloys ranged up to 7 percent (Roskill Information Services, Ltd.,1997, p. 108). Nonautomotive batteries, such as deep-discharge

industrial batteries, load-leveling batteries, standby emergency power supplies, and traction batteries (used for forklifts, baggage carts, and other vehicles) still commonly use antimonial lead grids, some of which contain as much as 11 percent antimony (Berndt, 1997, p. 157-158). The substantially longer life of antimony-containing batteries compared with calcium-containing batteries is a factor in choosing them for some industrial uses.

U.S. total consumption of antimony (primary metal plus secondary metal) in LA batteries was more than 25,000 t in 1965. Shortly thereafter, antimony began to be phased out of battery grids, and the amount used declined rapidly through the 1970s, then less rapidly through the 1980s, and finally stabilized in the latter part of the 1990s at about 8,000 to 9,000 t/yr, of which the primary antimony component was about 1,200 to 1,750 t/yr. In 1999, use of total antimony (primary plus secondary) in batteries amounted to nearly 80 percent of the metallic uses, or 19 percent of all uses.

BEARING METAL

Antimony is a key component in babbitt metal, a family of alloys used in the sleeve (or friction) bearings that are ubiquitous in all kinds and sizes of machines. The babbitt alloy is used as a low-friction liner in bearing shells of strong metals, such as bronze, cast iron, or steel. The liner may be as thin as 1 millimeter (mm) or, in the largest industrial machinery, as thick as 10 mm. In service, the liner is usually lubricated but must have properties that prevent galling or seizing of the moving parts at times of high transient loads or interrupted lubricant flow. Antimony, along with lead, tin, and a half dozen other metals, fits that requirement by virtue of forming bonds with iron that are of mixed metallic-covalent character and weaker than the metallic iron-to-iron bonds and, further, by having atomic radii that are significantly greater than that of iron, which lowers these metals' reactivity and mutual solid solubility with iron. In addition, the bearing alloy must be soft enough to embed foreign particles that would otherwise score the bearing journal or shaft, but strong enough to carry the applied load without distortion or fatigue-cracking. Tin-based babbitts are widely used in low-temperature (less than 130 $^{\circ}$C) bearings in compressors, gearboxes, automotive transmissions, and countless other machines. Lead-based babbitts are cheaper than the tin-based alloys but less corrosion-resistant and are normally used with oxidation-inhibited lubricants; they are used widely wherever their properties are adequate. In internal combustion engines, high-load crankshaft and connecting-rod bearings, which are normally formed from copper- or aluminum-based alloys, are sometimes electroplated with a 15- to 25-micrometer film of lead Babbitt to aid in the run-in of the bearings in a new engine.

U.S. consumption of antimony in bearing metal has declined continuously over the last half century; it appears to have stabilized in the 1990s in the range of 100 to 150 t/yr, far below the 2,500 t estimated for 1950. In 1999, use in bearings amounted to about 2 percent of the metallic uses of primary antimony and less than 0.3 percent of all uses. Possible substitutes for antimony-containing friction bearings exist for many, but perhaps not all applications in which babbitt is used. Metal substitutes include alloys of aluminum, copper, tin, and zinc, as well as cast iron, steel, and silver; in addition, porous aluminum, bronze, and iron are available. In some instances, organic polymers, such as nylon or polyimide, or other materials, such as silicon nitride, carbon-graphite, or aluminum oxide may be substituted. Finally, ball and roller bearings are candidates for selected uses. (Booser, 1992, p. 5-20; Roskill Information Services Ltd., 1997, p. 119-121).

SOLDERS

Antimony is a minor but important constituent of many soft solders, which are solders that melt at temperatures below 350 $^{\circ}$C. Solders referred to as tin-lead solders contain 0.05 to 0.50 percent antimony; those referred to as tin-lead-antimony solders contain 0.5 to 3.0 percent antimony. Antimony's function in these solders is to strengthen the solder and to suppress the formation of the low-temperature allotrope of tin, which otherwise would degrade the structural integrity of soldered joints at temperatures below the phase transition point (13 $^{\circ}$C). Lead-containing solders have been banned from use in the fabrication of food containers and from potable water systems in many of the developed countries. In the largest market for soft solders, the manufacture of electronic/electrical equipment, the concern about lead content is not connected with the use of the equipment, but rather with its disposal after being scrapped. Much electronic gear cannot be recycled economically and is either landfilled or incinerated; pollution of ground water or air by lead and antimony is a potential consequence. Two solders used widely in the electronics industry in manufacturing circuit boards are the eutectic 63 percent Sn-37 percent Pb solder, melting at 183 $^{\circ}$C, and the near-eutectic 60 percent Sn-40 percent Pb solder, melting over the range 183 to 190 $^{\circ}$C. These low-melting alloys can be used without harming electronic components or the circuit board materials and are otherwise well suited for rapid automated assembly processes. Efforts to replace these solders with lead- and antimony-free alloys and to modify the assembly processes as required are continuing. New formulations have been patented and some are in use, but the replacement proceeds slowly, and antimony-containing tin-lead solders are still the ones in

common use. During the last half century, use of antimony in solders in the United States has ranged between about 100 and 300 t/yr. In 1999, at an estimated 200 t, the use in solders accounted for about 5 percent of the metallic uses of primary antimony, or less than 0.5 percent of all uses of primary antimony. Proposed substitute solders usually consist of various combinations of bismuth, copper, indium, silver, tin, and zinc, most of which are used in small amounts in the conventional lead/antimony solders but in different proportions in the substitute solders (Rabin, 1997; Roskill Information Services Ltd., 1997, p. 115-118).

<div align="center">OTHER METALLIC USES</div>

As used in USGS Minerals Yearbooks in recent years, this category includes ammunition, cable covering, castings, sheet and pipe, and type metal. Consumption figures for the individual uses are withheld to avoid disclosing company confidential information. Collectively, they are estimated by the USGS to have accounted in 1999 for about 2,170 t of primary antimony.

Ammunition

Antimony has long been used as a hardener for the lead used in ammunition. Today, in the United States, its use is largely confined to small arms ammunition and shot intended mostly for sporting use.   Pollution of ground water, soil, and the food chain with toxic lead has been of concern for many years, and environmental regulations have led to the replacement of much of the lead shot, which contains as much as 2 percent antimony, with nonlead types, especially for use on waterfowl. Military firing ranges are now converting to tungsten bullets in response to environmental concerns. In the 1980s, when data were last published, U.S. consumption of primary antimony in ammunition ranged from less than 200 to about 500 t/yr. In 1999, in the United States, lead ammunition and shot for small arms contained, on average, about 1 percent antimony; this amounted to several hundred metric tons of the metal. Known substitutes for antimonial lead in small arms ammunition are 97 percent bismuth-3 percent tin alloys, steel, and tungsten (Brown, 2001).

Cable Covering

Some electrical power and communications cables, especially those used in tropical climates or under water, are sheathed in lead. Lead sheathing, which can be extruded easily and remains pliable indefinitely, provides an effective barrier to water or chemicals. When the cable is intended for environments in which it will be subjected to repeated flexing or vibration, antimony in amounts up to 1 percent is alloyed with the lead. The several substitutes for antimonial lead for use in less harsh environments have reduced the demand for the alloy during the last few decades. Laminated aluminum is used to sheath high-voltage power cables, and organic polymers, to sheath most communications cables (Prengaman, 1995, p. 117-118; Roskill Information Services Ltd., 1997, p. 125).

Rolled and Extruded Alloys

Wrought lead-antimony alloys that contain about 2 to 8 percent antimony are resistant to atmospheric corrosion and find use in building construction in flashing, gutters, moisture barriers pipe, and roofing. In the chemical industry, alloys that contain from 4 to 15 percent antimony provide protection against various strong chemicals, especially hot sulfuric acid or sulfate liquids, and are used for pumps, tank linings, and valves. Alloys that contain from 4 to 6 percent antimony are used for radiation shielding, and alloys that contain from 1 to 4 percent antimony are used to make collapsible tubes for packaging pastes and ointments. Stainless steels and polymers are substitutes for antimony-lead in some of these uses. Altogether, these uses account for only a small amount of the antimony consumed (Prengaman, 1995, p. 118).

Casting Alloys

Tin-antimony-lead alloys, such as pewter, Britannia metal, and type metal, possess low melting points, good fluidity in the molten state, and high hardness and solidify with minimal or no shrinkage. These attributes make them ideal for a variety of specialty castings of decorative objects from belt buckles and candlesticks to coffin trim. Alloyed with bismuth, lead, and tin, antimony is a component of some of the fusible alloys used in fire safety devices and as jigs for machining metals. Type metal, which is used in letterpress printing, was once a very important antimony alloy (U.S. consumption at the end of World War II was 1,100 to 1,700 t/yr) but it has been made obsolete by the advent of new printing methods. Consumption in 1990, the last year for which data were published, was 3 t.

Miscellaneous Metallic Uses

Antimony is used in very small amounts (less than 0.1 percent) in copper-based alloys, such as admiralty brass, naval brass, and leaded muntz metal, to prevent dezincification (Li and others, 1992, p. 377). Finally, 50 ppm antimony added to ductile iron nodularizes graphite fully, and 0.05 percent antimony added to gray cast iron stabilizes the carbide content. Small quantities of high-purity antimony are used in some semiconductor materials, and in one process for the manufacture of rewriteable digital video discs (DVD's) (Roskill Information Services, Ltd., 1997, p. 126-127).

NONMETALLIC USES

The compounds of antimony, especially the trioxide, are used in a variety of ways—as stabilizers for several commodity plastics; as a catalyst precursor in the production of an important polyester plastic; as pigments in enamels, paints, and rubber; as a antisolarant, decolorizer, and fining agent (bubble remover), in glass; and, with halogenated hydrocarbons, as flame-retardant synergists for adhesives, plastics, rubber, and textiles. The consumption pattern for primary antimony in nonmetallic uses in the United States in 1999 is shown in figure 8.

(64.0%) Flame retardants
(4.6%) Other uses
(9.9%) Pigments
(10.8%) Ceramics and glass
(10.8%) Plastics stabilizers and catalysts
Estimated total 35,330 metric tons

Figure 8: Estimated U.S. consumption of primary antimony for nonmetallic products in 1999. [Based partly on data from U.S. Geological Survey, 2000]

FLAME RETARDANTS

Materials that require flame retardance are usually organic polymers whether natural or artificial. Flame (or fire) retardance, which is the largest use for primary antimony, accounts for about 57 percent of consumption in the United States and 60 percent, on average, in the world. The consumption pattern for antimony used in flame retardants (all of which is primary antimony) is shown in figure 9. With respect to plastics, which is the largest market, the ones in need of flame retardants are the low- to medium-cost commodity plastics, such as flexible polyvinyl chloride (PVC), the polyolefins (p-ethylene, p-propylene, and p-butylene), polystyrene, polyethylene terephthalate (PET), acrylonitrile-butadiene-styrene (ABS), and polyurethanes. The higher priced engineering polymers tend to be inherently more fire resistant than the commodity polymers, some of which (PVC, for instance) are rendered more flammable by the plasticizers that must be added to them to make them usable. Antimony in the form of the trioxide, the pentoxide, or (especially) sodium antimonate is either compounded in flammable materials during their synthesis or added to them after manufacture and with one exception (cellulosic fibers, such as cotton) is always used in association with halogen-bearing compounds. Antimony trioxide usually accounts for about one-fourth to one-third of the weight of the antimony-halogen combination. The weight of the trioxide as part of the above-mentioned compounded polymers ranges from about 1.5 percent to as much as 10 or 12 percent.

(88.1%) Plastics

(2.2%) Adhesives
(3.6%) Textiles
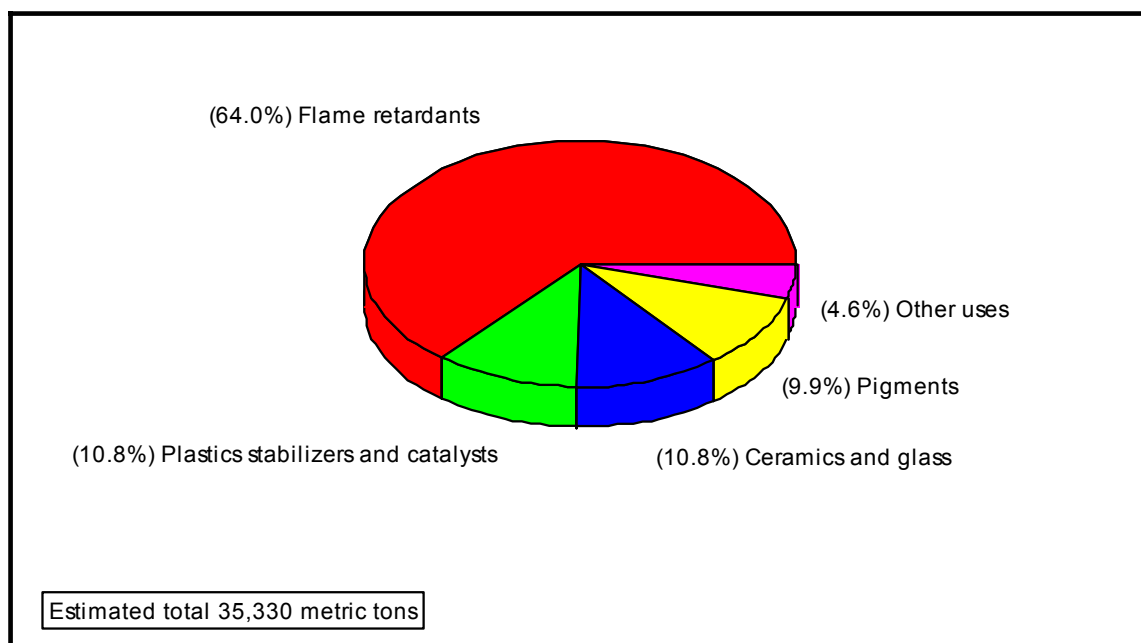(6.1%) Rubber

Estimated total 22,600 metric tons
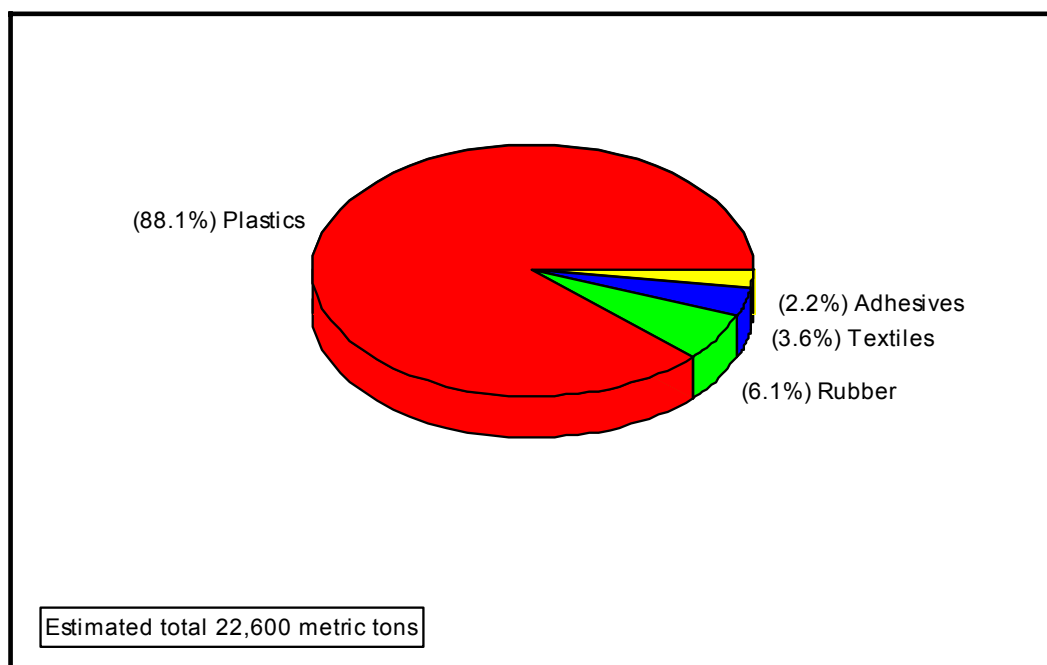
Figure 9: Estimated U.S. consumption of primary antimony for flame retardants in 1999. [Based partly on data from U.S. Geological Survey, 2000]

The antimony-halogen combinations compete with several other types of flame retardant, as listed in table 4. They are effective and cost-efficient and well-established in a variety of end-product markets. By inhibiting complete combustion, however, halogen flame retardants of all types generate noxious smoke, which is commonly more lethal to building occupants than the flame itself. Those formulated with antimony have the added disadvantage of containing a heavy metal, which may leach into the environment upon discard of the flame-retarded product.

Table 4. U.S. flame-retardants market volume in 1991.
[TPC Business Research Group, *in* Gann, 1993, p. 934]

Group	Thousand metric tons	Million dollars
Brominated hydrocarbons	36	160
Aluminum trihydrate	170	85
Antimony trioxide	25	85
Phosphate esters	18	50
Halogenated phosphates	16	46
Brominated bisphenol A	18	37
Chlorinated hydrocarbons	15	31
Borates	8	10
Magnesium hydroxide	3	6
Total	309	510

Combustion is an exothermic reaction maintained by internally generated free radicals and radiant heat. "Halogen-containing flame retardants act by interfering with the radical chain mechanism in the gas phase [the flame] (Troitzsch, 1990)." When used by themselves, halogen flame retardants must be used in large amounts—about 40 percent by weight is needed to impart acceptable fire retardancy to plastics—and such a large content tends

to degrade the properties of the plastics. This problem is avoided by adding antimony oxide, which works synergistically with the organic halogens, reducing the amount of flame retardant needed and reducing also the overall cost of treatment. The mechanism by which the antimony-halide synergists work has not been definitively explained; they may actually work in several ways—cooling by means of endothermic processes; forming an insulating layer of carbonaceous char; diluting the reactant gases; and acting as radical traps in the gas phase. The last mechanism is thought to be of particular importance, and much of the effectiveness of antimony may lie in the stepwise endothermic generation of antimony oxychloride and antimony trichloride. Both of those compounds supply the active components (halide radicals) over an extended temperature range ($\sim$250–565 ^{o}C) and for a longer period of residence in the flame than if the halides were derived directly from the organic halogen component of the fire-retardant mix (Touval, 1993, p. 941).

Rubber and other elastomers are flame retarded with halogen compounds and 5 to as much as 30 percent antimony trioxide. PVC insulation on electrical wires and cables is flame-retarded with about 3 percent antimony oxide. Canvas, carpets, carpet padding, drapes, tenting, and other (usually heavier) textiles are fire retarded with about 7 percent antimony oxide combined with chlorinated paraffins and/or PVC latex (U.S. Antimony Corp., undated). Paper can be fire retarded by the addition of from 5 to 25 percent antimony oxide plus a chlorinated compound. Paints can be fire retarded by replacing some of the pigment with antimony oxide and adding a chlorinated paraffin to the paint vehicle.

U.S. consumption of primary antimony in flame retardants has been growing briskly since the 1960s. In 1999, it accounted for about 57 percent, or nearly 23,000 t, of primary antimony consumption.

The antimony content of a flame retardant can be reduced by replacing part of it with boron, molybdenum, phosphorus, silicon, tin, or zinc compounds. These mixed-metal synergists have their own advantages, such as the smoke-suppressant ability of the molybdenum compounds (Touval, 1993, p. 941-953). Some, such as boron, silicon, and tin, may also be more acceptable environmentally in that they are not, like antimony, members of the "heavy metal" group of elements, which are widely regarded as pollutants.

<div align="center">PLASTICS ADDITIVES</div>

Stabilizers

Many common plastics are susceptible to degradation by heat and ultraviolet light (UV) and must be protected during processing (at temperatures on the order of 150 to 300 ^{o}C) and during the service life of products made from them by the addition of compounds known as stabilizers. Some stabilizers protect against both heat and UV, some against one or the other. In general, UV stabilizers cannot be effective unless satisfactory heat stabilization also is provided. Most of the market for stabilizers in the United States (perhaps from 85 to 90 percent in terms of tonnage) is for the treatment of PVC. PVC is one of the three or four largest volume commodity plastics; it is a protean material used for a wide array of products from food wrap to clear water bottles, artificial leather, toys, electrical wire and cable insulation and to drainage and water supply pipe, to name only a few. Antimony mercaptides were found in the 1950s to be effective heat stabilizers for PVC, especially rigid forms of the plastic. They competed with organotin mercaptides during the years when tin prices were very high, but after the decline of the tin price in the 1980s, lost some market share (Mesch, 1993, p. 1,071-1,073). They are also less efficient than organotin stabilizers, are subject to photodecomposition and hence restricted largely to underground PVC pipes and conduits, and have the added disadvantage of containing a heavy metal with the attendant environmental concerns. At present, they compete with five or six other families of stabilizers and account for only a few percent of the tonnage market. Their principal competitors are calcium-zinc compounds in Europe and organotin compounds in the United States and Japan (Roskill Information Services, Ltd., 1997, p. 142). Stabilizers and PET catalysts are lumped together in "plastics" in USGS statistics on antimony; a separate consumption figure for stabilizers is not provided.

Catalysts

Antimony in either the trioxide or the triacetate form is used as a polycondensation catalyst in the late-stage polymerization of PET, which is a large-volume commodity plastic used in bottles, films, food packaging, and many other products. The antimony compounds, along with germanium dioxide, are the preferred catalysts for PET. Germanium dioxide gives a product with better transparency and colorlessness than does antimony but is too expensive ($750 per kilogram in 1999) for many uses of PET; titanium alkoxides are effective but cause unacceptable yellowing of the polymer. Antimony oxide is the commonly used catalyst in the United States (East and Golden, 1997, p. 615-616).

CERAMICS AND GLASS

Although antimony's uses in ceramics and glass are commonly lumped together, as in USGS consumption statistics, it is used for different purposes in the two classes of materials. Most, perhaps on the order of two-thirds, of the antimony consumed in the ceramics and glass category goes into glass where it performs one or more functions. Perhaps most important is its use as a fining agent/decolorant/antisolarant for high-quality transparent glass. Antimony oxide, sodium antimonate, and other fining agents, such as arsenious oxide and sodium sulfate, decompose as the temperature of the glass melt rises and over-saturate the melt with gases. These gases form large bubbles that rise through the melt, gathering and coalescing with the small isolated bubbles of carbon dioxide, nitrogen, and water vapor left over from the early melt stage. As the rate of rise of bubbles through the melt is directly proportional to the square of the bubble radius, the resultant larger bubbles are better able to escape to the surface of the viscous melt and, in the process, effectively stir and homogenize the melt. The largest application for such clarified, perfectly transparent glasses is the display screen (or panel) of the cathode ray tube (CRT) used in computers and television receivers. Antimony oxide is also an effective decolorizing agent and antisolarant. Added to the melt, it counters the green tint caused by the presence of trace iron impurities and protects the clear glass during its lifetime in use against colorization caused by prolonged exposure to sunlight or fluorescent lighting. Finally, together with other compounds, antimony sulfide is used as a glass colorant that yields amber, green, or red glass.

In ceramics, a mixture of antimony trioxide and tin oxide can be used to produce a gray-to- blue color, and antimony trioxide with titanium dioxide yields a yellow color. High-tint antimony trioxide or sodium antimonate are used in conjunction with titanium dioxide as opacifiers in vitreous enamel frits and, to a small extent, in low-firing glazes. In all these uses in ceramics and glass, antimony compounds may be substituted at the expense of cost effectiveness, efficiency, or long-term performance. Consumption of primary antimony for glass and ceramics production in 1999 is estimated by the USGS to have been about 3,800 t (Roskill Information Services Ltd., 1997, p. 146-151; 2001, p. 159-166; U.S. Antimony Corp., 2000.)

PIGMENTS

As a white pigment for exterior paints, where its resistance to weathering ("chalking") made it valuable, antimony trioxide has been supplanted in the United States by titanium dioxide. It may still used in a few oil-based exterior paints and enamels. It is, however, used in significant quantities as an antisolarant, or color stabilizer, where it is important to maintain color intensity and to avoid change of hue, such as in the yellow paints used for school buses and in the yellow striping applied to road pavements.

Pigments made from the trisulfide and the pentasulfide are used for coloring rubber black and shades of yellow, orange, and red.

Electroconductive pigments of tin oxide doped with antimony have been introduced in recent years for incorporation in the plastic coatings that protect delicate computer and other electronic components from electrostatic arcing (Roskill Information Services Ltd., 1997, p. 151-152; U.S. Antimony Corp., 2000).

Altogether, pigments are estimated by the USGS to have accounted for the consumption of about 3,500 t of primary antimony in the United States in 1999.

OTHER NONMETALLIC USES

The following are small but well-established uses of antimony compounds:
- Antimony is added to some fluid lubricants to increase their chemical stability.
- Antimony is used as a passivating agent for contaminant nickel in the refining of sour crude oil.
- Antimony oxide is used as a phosphor in fluorescent lamps.
- Antimony pentasulfide has been used as a vulcanization agent for the production of red rubber (Wyche, 1976). Antimony trisulfide is used in primers for ammunition and high explosives and as a lubricant in automotive brake and clutch linings, and in fireworks and (in Asia) in matches.
- Potassium pyroantimonate is used as a cross-linking agent for guar gum, which is a natural gum used as a thickening agent in various aqueous liquids and as a sizing material for paper and textiles.
- Antimony trichloride and pentachloride are used as reactants in organic chemical reactions, most notably in the manufacture of freons.

- Tartar emetic (hydrated potassium antimonyl tartar) apparently is no longer used in the United States, but may be elsewhere. In the past it was used as a pesticide; a treatment for stomach disorders; a treatment for the parasitic disease, leishmaniasis; and a mordant for some acid textile dyes.

In total, these uses are estimated by the USGS to have accounted for the consumption of roughly 1,630 t of primary antimony in the United States in 1999.

TRENDS IN USE

As shown in figure 6, apparent consumption of primary antimony in the United States has grown at a substantial rate (about 5.6 percent per year) since the early 1980s. Although the data collected by surveying the using industries are not sufficiently reliable to track growth rates for individual end uses, even the consumption for metallic products, which had declined precipitously in the 1970s, seems to have grown modestly, probably led by consumption in antimonial lead used for ammunition and perhaps for cable covering and sheet and pipe. Reported data suggest that consumption for nonmetallic products other than flame retardants may have grown a little in the 1990s. The main impetus to growth in the 1980s and 1990s, however, came from the expanding use of antimony flame retardants in plastics, which was strong enough to offset static or declining use for antimony in flame retardants for other materials.

The trend in overall antimony consumption in the United States for the next several years will be determined largely by demand in the largest use sector—flame retardants, and, to a lesser degree, by growth in the much smaller market for PET catalysts. Domestic consumption of antimony for flame retardants may grow at low single-digit annual rates; consumption for PET catalysts, which starts from a much smaller base, will tend to grow faster, but still at low single-digit rates. For both of these uses, however, growth will be considerably faster in the industrializing countries of the world where, in contrast to Japan, the United States, and Western Europe, markets are not as mature. The use of antimony in plastics stabilizers will likely remain static or lose ground to competitor stabilizers. Growth of antimony consumption in the manufacture of glass and ceramics will continue to be dominated by the use in CRT glass, the production of which Roskill Information Services Ltd. (2001, p. 166) believes will grow on the world market "in the medium-term future" at rates of 7 percent per year for computer monitors and 3 percent per year for television displays. Consumption in pigments will probably remain static in the years ahead as antimony maintains its share in its niche markets.

Nearly all the metallic uses of antimony are in the form of antimonial lead and are expected to decline as the use of lead is further restricted by environmental considerations. Among the metallic uses, only the use in solders is likely to grow and that from a small base. Use in LA batteries probably will remain static or even decline as the shift to maintenance-free (and thus, antimony-free) batteries continues, and the supply of secondary antimony from scrapped batteries remains ample. Use in ammunition and shot is expected to continue to decline.

SUBSTITUTES FOR ANTIMONY

In metal products, many alloys are available to substitute for antimony-containing alloys. In the largest metallurgical market, hardened lead, various combinations of calcium, copper, tin, and other metals compete successfully with antimony as hardeners. Aluminum and organic polymers substitute for antimonial lead for cable covering, tungsten substitutes for antimonial lead in bullets, and aluminum, cadmium, lead, tin, and organic polymers compete with antimony in friction bearings.

At least eight other types of flame retardants compete with antimony trioxide-halogen types. Five types of plastics stabilizers, which contain barium, cadmium, calcium, lead, tin, and zinc in various combinations, compete with the antimony-containing mercaptides. Compounds of cadmium, chromium, tin, titanium, zinc, and zirconium compete with antimony in pigments and enamels.

INDUSTRY AND MARKET

Antimony is mined either as a principal product or a byproduct in at least 15 countries. Mine production is concentrated very heavily in China, which accounted for 85 percent of the world total in 2000 (U.S. Geological Survey, 2001). The companies or organizations that mine antimony range widely in size according to whether they are solely producers of antimony, in which case they are likely to be small, or are large metal mining companies for whom antimony is only one of several products and byproducts. Worldwide, there are hundreds of antimony mines, most of them in China. The 16 largest mines or mining complexes, which range in annual production from 1,000 to

about 13,450 t of antimony, accounted for nearly 40 percent of world mine production in 1996 (Roskill Information Services Ltd., 1997, p. 17).

China dominates the production of antimony metal as completely as it dominates mine production, with production in the only other sizeable producers, Kyrgyzstan, Mexico, and Thailand, each an order of magnitude smaller than in China. Production of antimony trioxide, which is a more important commodity volumetrically, is shared more equally between producing and consuming countries. The United States accounts for about one-third of commercial-grade trioxide production, China for about one-quarter, and France, Japan, Belgium, Mexico, and South Africa, in descending order, for most of the remainder (Roskill Information Services Ltd., 1997, p.19, 24). Some of the oxide, such as that produced in Bolivia and South Africa, requires upgrading for some uses.

Secondary antimony is derived almost entirely from lead-based alloys and is recovered at secondary and a few primary lead smelters. The largest producers are in the industrial countries, which have the greatest concentration of LA vehicle batteries. The United States, which is by far the largest producing country, accounts for more than one-third of world production.

The antimony mining sector in the United States in recent years consisted of only the Sunshine Mine, where antimony was a byproduct of silver production until the mine was shut down and placed on care and maintenance status early in 2001. The domestic industry that produces refined antimony products also has shrunk in recent years as foreign refined materials have become more readily available, especially from China. By the spring of 2002, no antimony metal was being produced domestically, and just two companies were producing refined trioxide and possibly sodium antimonate (OxyChem Corp., LaPorte, TX, and U.S. Antimony Corp., Thompson Falls, MT).

Because antimony mine production is concentrated in China, South Africa, Bolivia, and Russia and consumption is concentrated in the industrial countries, most antimony raw materials and much of the refined materials enter international trade. Much of the high-grade metal and oxide are produced in the consuming countries, from imported concentrates, metal, or crude oxide. The trend during the past two to three decades has been towards a decrease in the flow of ore and concentrate and a marked increase in the movement of metal and oxide. This trend, which has been fueled by the rapid growth of Chinese production of metal and oxide, may be seen, for the United States, in figure 10. Because the United States, Japan, and several other industrial countries are substantial producers of refined antimony trioxide, the trade flow of this material is less uni-directional than the trade in metal.
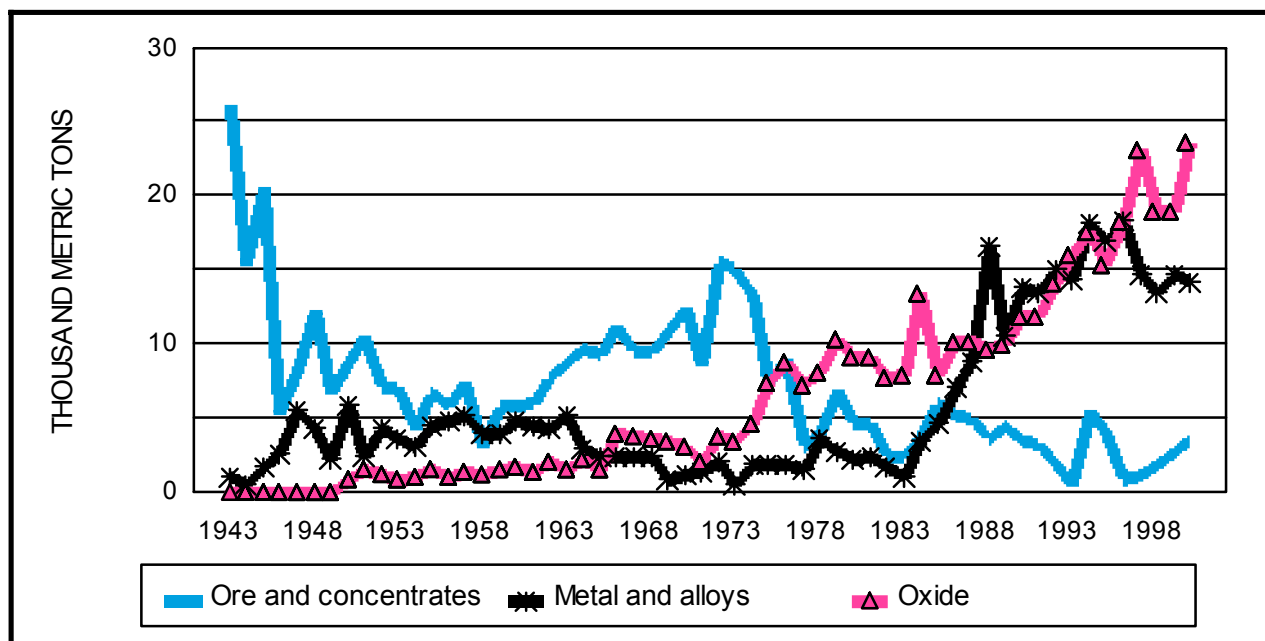
Figure 10: U.S. imports of antimony, 1943-2000. [Data from U.S. Bureau of Mines 1943-95; U.S. Geological Survey, 1996-2001]

The past three decades in the antimony market have been characterized by greatly increased volatility in price. In the 1970s, a combination of relatively inflexible and concentrated mine supply, and demand in the using countries driven by the rapidly rising production of plastics and the establishment of laws that govern flammability of textiles

and other materials prompted temporary market tightness that gave rise to price spikes (fig.11). From the mid-1980s to 2000, price instability has become more and more a consequence of the concentration of production in one country, China, and the fluctuations in Chinese production or shipments attributable to natural events, such as the widespread flooding in southern China in 1994, or changes in government policy, such as the imposition of a 20-percent export tax on antimony ores and concentrates, which contributed to the steep price rise in 1994-95. After 1995, the price of antimony fell steadily through 1999, which caused revenue to fall well below mining costs in China.

Figure 11: Average annual price of antimony in the United States. [Prices 1900-98 from Carlin, 1999; prices 1999-2001, Carlin 2002]

This uneconomic condition prompted the Chinese government to suspend the issuance of new mining licenses through 2000, to limit the export of antimony to 60,000 t in 2000, and to crack down on smuggling. At the beginning of the 21st century, the antimony mining industry worldwide is characterized by over-capacity and insufficient revenue to sustain operations at some locations.

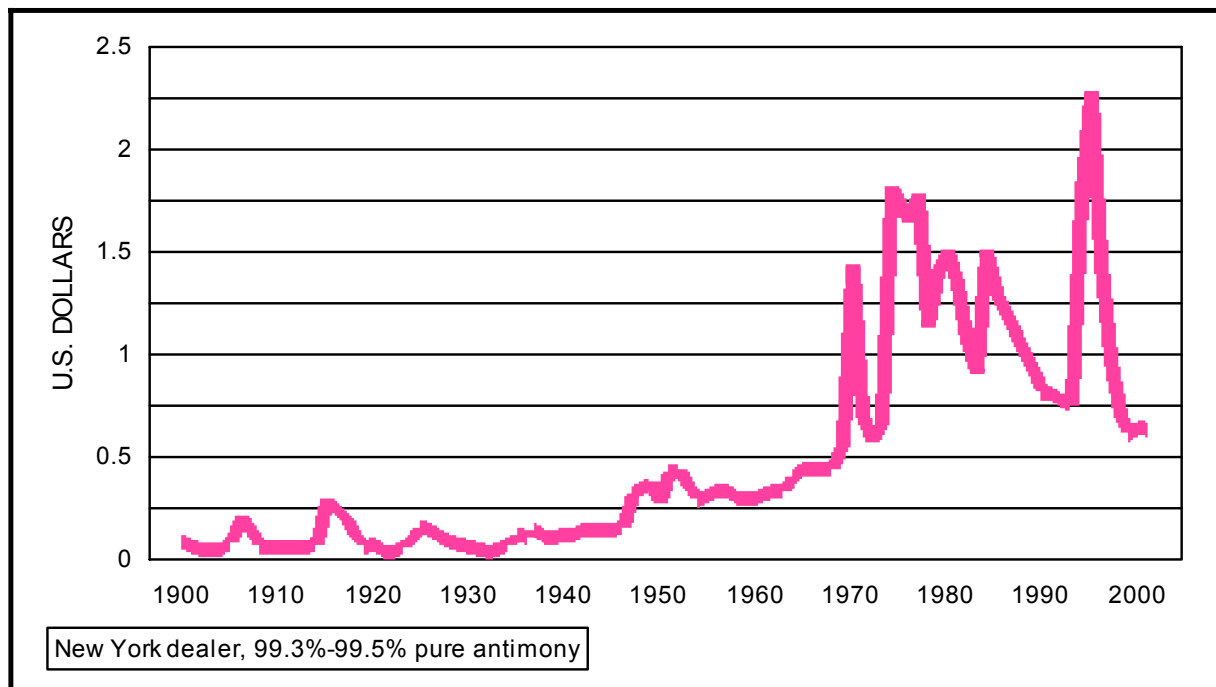The antimony-using industries, which are located primarily in the industrial countries, consist principally of the transportation and communications industries (LA batteries and plastic insulation on electrical wires), the plastics products industries (flame-retardants, catalysts, heat/UV stabilizers), the ceramics and glass industries (pigments, glazes), and the pigments industries (coatings, paint). The United States has the largest concentration of the using industries, which consume nearly 40 percent of the world's antimony mine production.

Antimony metal is traded by more than 200 companies worldwide, and ores and the trioxide are each traded by nearly 100 companies. Many of the companies deal in two or more forms of antimony and in other commodity metals and minerals (Moreno, 1997, p. 431–437). In addition, producers sell directly to their larger industrial customers.

ANTIMONY AND THE ENVIRONMENT

Breathing air that contains high levels of antimony for lengthy periods can irritate the eyes and lungs and can cause problems with the lungs, heart, and stomach (U.S. Agency for Toxic Substances and Disease Registry, 1995). The occupational exposure limit is 0.5 milligram of antimony per cubic meter of air for an 8-hour workday, 40-hour workweek. The maximum allowable level of antimony in drinking water in the United States is 0.006 ppm. Whether antimony is a carcinogen has not been determined. Most of the antimony released to the environment eventually makes its way into soils where it attaches to minerals or compounds that contain aluminum, iron, or manganese (U.S. Department of Health and Human Services, 1995). Most antimony compounds appear not to

undergo bioconcentration. In urban air, the main sources of antimony pollution are neither the producers nor the fabricators of antimony and products derived from it, but rather the burning of fossil fuels in automotive vehicles, powerplants, and incinerators (U.S. Environmental Protection Agency, 2001).

The U.S. Environmental Protection Agency's Toxic Release Inventory for the period from 1987 through 1993 showed that U. S. industrial plants released more than 900 t/yr of antimony in all forms to the land and about 25 t/yr to surface and ground waters. Of the antimony released to land by major industries, primary copper smelters accounted for about 60 percent; primary smelters for other nonferrous metals, 20 percent; secondary nonferrous smelters, 7 percent; and petroleum refineries, 2 percent. The remaining 11 percent was attributed to the manufacture of various antimony products. Geographically, 85 percent of the release to land in the 1987-93 period took place in Arizona, Montana, and Texas as a result of the concentration of nonferrous smelting in those States (U.S. Environmental Protection Agency, 2001).

Among the major releases of antimony to terrestrial waters, those from petroleum refineries accounted for 34 percent; the manufacture of synthetic fibers, 8 percent; and the smelting of nonferrous metals other than copper, 5 percent. All other individual releases to terrestrial waters were much smaller (U.S. Environmental Protection Agency, 2001).

The postconsumer release of antimony from scrapped end-use products is also of importance. There are concerns, especially in Europe, about the leaching of antimony pigments, heat stabilizers, and flame retardants from discarded plastics products. These concerns have contributed to a shift to calcium-zinc stabilizers in Europe and to tin-based stabilizers in the United States and Japan. Efforts to ban halogenated flame retardants, which include the synergistic formulations that contain antimony oxides, are continuing in several western European countries.

SUPPLY, DEMAND, AND SUSTAINABILITY

For most of the 20th century, the antimony market was one of the more unstable metal markets. Except for the sudden imposition of wartime demand, the instability originated from short-term fluctuations in supply. China dominated the supply for most of that time, and shipments, typically metal and crudum (impure sulfide) rather than ore, tended to be irregular, thus keeping prices in the consuming countries unsettled. Before World War II, when many Chinese chose to invest in the traditional export metals rather than banking their money, the antimony market, being small, was easily affected by speculation. The multiplicity of small independent mines and the lack of organization among the owners, however, tended to make supply responsive to demand; the higher cost mines were worked or left idle according to the price of ore. The situation in Bolivia, which was the second most important producer through much of the century, was much the same.

CURRENT SUPPLY AND DEMAND

At the end of the century, antimony mine output was still dominated by a handful of countries and completely overshadowed by China, which has accounted for more than 80 percent of world output in every year since 1995 (fig. 12). Volatility, as reflected in the price of antimony metal, has actually increased in the past three decades (fig. 11). Supply-distribution relationships for the United States are shown for 1999 in figure 13, and for the last half-century, in table 5. Salient observations include the following:
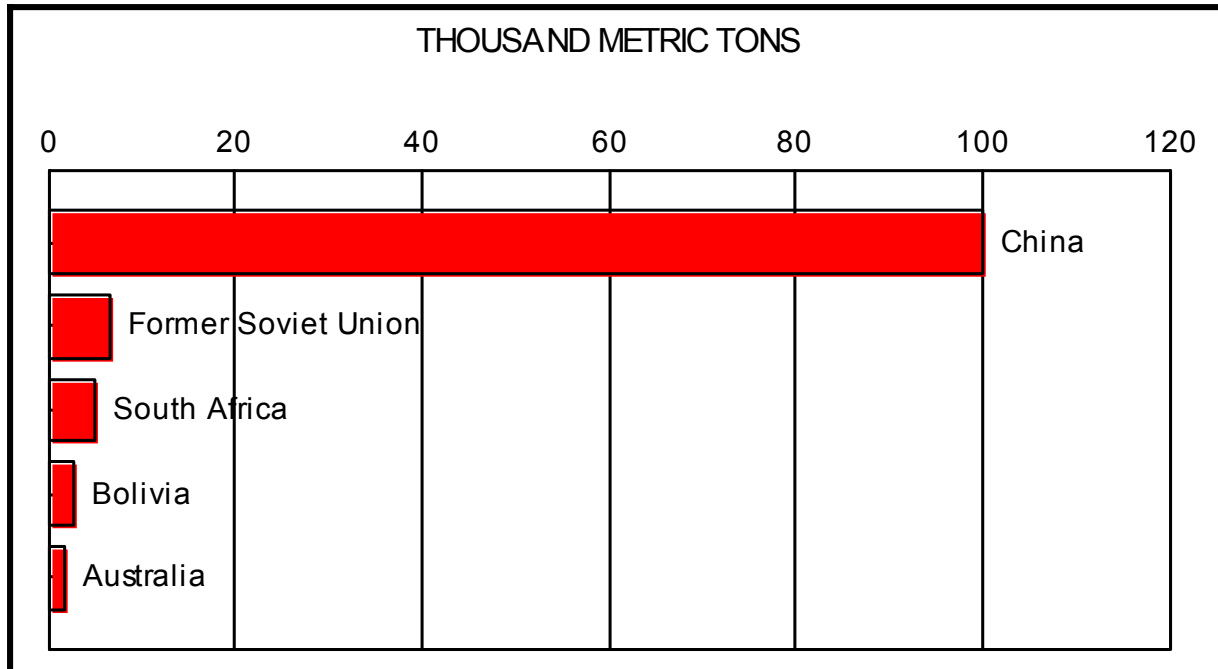
Figure 12: Antimony mine production in 2000, principal producing countries. [Data from U.S. Geological Survery, 2001]

Raw materials

Domestic ores
450

Imports, ore

Mexico	1,290
Australia	1,070
China	398
Other	112
Total	2,870

Imports, crude oxide

Mexico	2,950
Bolivia	1,470
Chile	229
Guatemala	207
Total	4,860

Domestic scrap
7,500 e/

Total supply, refined metal
50,500

Primary refined or processed
8,180

Imports, refined metal

China	13,100
Mexico	736
Singapore	400
Peru	209
Other	355
Total	14,800

Imports, oxide

China	7,860
Belgium	2,730
South Africa	2,680
Other	974
Total	14,200

Secondary refined (antimonial lead)
7,500 e/

Sales from National Defense Stockpile
5,790

Distribution of supply
50,500

Domestic fabrication

Flame retardants	24,200
Lead-acid batteries	9,100
Ceramics and glass	4,000
Plastics	4,000
Pigments	1,500
Other	4,100
Total	46,900

Exports, metal and scrap

Mexico	173
Canada	115
Other	67
Total	355

Exports, oxide

Canada	1,180
Mexico	571
China	312
Other	1,130
Total	3,190

Net additions to stocks
100

Figure 13. U.S. antimony supply and demand, 1999. [In metric tons, contained antimony. E. Estimate. Data on foreign trade in manufactured products are excluded. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown. Domestically refined primary antimony includes 4.860 tons of imported crude oxide that was upgraded. As an approximation it is assumed that all secondary refined metal recovered from old scrap is reused in lead-acid batteries. Estimates of full industry coverage for domestic fabrication are based on partial reports from industry plus information from industry and the trade press.]

Table 5. Unfabricated antimony: U.S. supply-demand relationships and consumption pattern, 1950-99.

[In metric tons, contained antimony. NA, Not available. ---, 0. W, Withheld to avoid disclosing company proprietary data; included in "Other uses." Data include estimates. All data are rounded to three significant digits; because of independent rounding, they may not add to totals shown. Note change at 1995 from 5- to 1-year intervals]

	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	1996	1997	1998	1999
Components of U.S. supply														
Refined/processed, primary 1/:														
Domestic antimony ores	2,260	574	576	767	1,020	804	311	300	250	262	242	356	498	449
Domestic lead ores (antimonial lead)	2,040	1,190	414	905	543	243	16	---	---	---	---	---	---	---
Imported ores and concentrates	8,840	6,780	5860	9,400	12,500	7,550	4,750	6,020	3,450	4,260	1,000	1,300	2,020	2,870
Total primary	13,150	8,540	6,850	11,100	14,100	8,600	5,080	6,320	3,700	4,520	1,240	1,660	2,520	3,320
Refined production, secondary:														
Old scrap 2/	16,500	18,300	15,800	19,700	13,500	10,200	10,900	8,160	10,700	9,900	7,100	6,900	7,000	7,500
Total refined/processed	29,700	26,900	22,700	30,800	27,600	18,800	16,000	14,500	14,400	14,400	8,340	8,560	9,520	10,800
Imports, refined antimony metal & alloys	5,960	4,570	4,930	2,400	1,170	1,920	2,350	4,650	13,900	16,900	18,300	14,800	13,500	14,800
Imports, oxide 3/	880	1,680	1,800	1,650	3,230	7,520	9,270	8,000	12,000	15,400	18,300	23,200	19,100	19,100
Sales from U.S. Govt. Stockpile	---	---	---	816	---	---	---	842	---	1,130	4,300	2,930	4,160	5,790
Net deliveries from industrial stocks	1,920	---	---	---	---	---	---	782	---	300	---	400	200	---
Total U.S. supply	38,400	33,100	29,400	35,600	32,000	28,200	27,600	28,800	40,400	48,200	49,200	49,900	46,500	50,500
Distribution of U.S. supply														
Exports, metal, alloys, waste, scrap	140	192	204	13	493	308	411	328	441	1,210	346	489	674	355
Exports, oxide	---	143	617	---	329	218	272	803	7,140	6,590	3,990	3,230	3,270	3,190
Purchases for U.S. Govt. Stockpile	---	181	1,960	---	---	---	---	---	---	---	---	---	---	---
Net additions to industrial stocks	---	1,090	18	1,200	2,280	2,960	1,150	---	1,920	---	400	---	---	100
Apparent consumption	38,300	31,500	26,600	34,400	28,900	24,700	25,800	27,600	30,900	40,400	44,500	46,200	42,500	46,900
Total Distribution of Supply	38,400	33,100	29,400	35,600	32,000	28,200	27,600	28,800	40,400	48,200	49,200	49,900	46,500	50,500
Consumption of primary antimony only 4/														
Flame retardants	611	965	901	1,670	2,170	4,690	NA	NA	NA	NA	NA	NA	NA	22,600
Lead-acid batteries	4,030	4,750	3,990	5,790	4,760	4,140	NA	NA	NA	NA	NA	NA	NA	1,600
Ceramics and glass	3,380	1,620	1,260	1,570	2,230	1,220	NA	NA	NA	NA	NA	NA	NA	3,800
Plastics stabilizers and catalysts	1,220	608	775	1,250	2,040	1,350	NA	NA	NA	NA	NA	NA	NA	3,800
Pigments	0	1,020	981	725	747	396	NA	NA	NA	NA	NA	NA	NA	3,500
Solder	268	104	99	207	350	165	NA	NA	NA	NA	NA	NA	NA	200
Bearing metal and bearings	2,510	659	614	696	589	497	NA	NA	NA	NA	NA	NA	NA	100
Ammunition	29	20	W	45	158	313	NA	NA	NA	NA	NA	NA	NA	W
Other uses	9,730	3,430	2,160	2,770	2,360	1,770	NA	NA	NA	NA	NA	NA	NA	3,800
Total estimated primary consumption	21,800	13,200	10,800	14,700	15,400	14,500	14,900	19,500	20,200	30,500	37,400	39,300	35,500	39,400
Total consumption, LA batteries only 5/	20,500	23,100	19,800	25,500	18,300	14,300	10,900	NA	NA	NA	NA	NA	NA	9,100

1/ Inferred from quantities of raw materials available; reported data not used because they include upgrading, which is not distinguishable from refining to commercial grade.
2/ Includes imported scrap, if any. Published old scrap/new scrap breakdown is not available after 1994; thus 1995-99 figures are estimates.
3/ Part of the oxide imported in most years is impure and must be refined. Estimates of the impure oxide are available only for 1998 (5,457 t) and 1999 (4,856 t) only.
4/ Data have been adjusted to match total reported consumption to total apparent consumption. Data for individual end uses for years after 1975 were considered too unreliable to use. Those shown for 1999 are estimates; however, the figure for "Lead-acid batteries" is based partly on reported figures.
5/ Total of primary + secondary metal. As an approximation, it is assumed that all secondary metal recovered from old scrap goes into lead-acid batteries.

- Domestic antimony and lead ores have never satisfied more than a small part of the demand for antimony, and in 1999, satisfied only about 1 percent of demand. Not shown in the table, but evident in figure 14, is the dedication of the domestic smelting industry in the 1990s to the production of trioxide, rather than metal products.
- Imports of antimony trioxide have been climbing steadily since the early 1970s. Imports of metal have been climbing steeply since the early 1980s. Imports of ore and concentrate, which had been the most important category of imported antimony raw materials until the mid-1970s, now account for less than 10 percent of imported antimony (fig. 10).
- The quantity of antimony recycled annually has been drifting downward since about 1970 as low-maintenance and maintenance-free LA automotive vehicle batteries, which contain little or no antimony, have gradually replaced the old vented battery. This has happened despite substantial growth in the number LA batteries in use.
- In recent years, sales of antimony from the U.S. National Defense Stockpile have become an important component of domestic supply; the inventory is expected to be exhausted in a few years.
- Exports of oxide, which had never been more than a few hundred tons, rose precipitously in the late 1980s to more than 7,000 t in 1990; they retreated part way and then peaked again at about 6,500 t in 1994-95 before stabilizing at about 3,000 t between 1997 and 1999.
- Consumption of secondary antimony followed approximately the same course as has been described for recycled antimony because most battery lead is recycled metal. Consumption of primary antimony began to grow rapidly in the early 1980s and is responsible for the overall growth of antimony consumption in the past two decades (fig. 15).
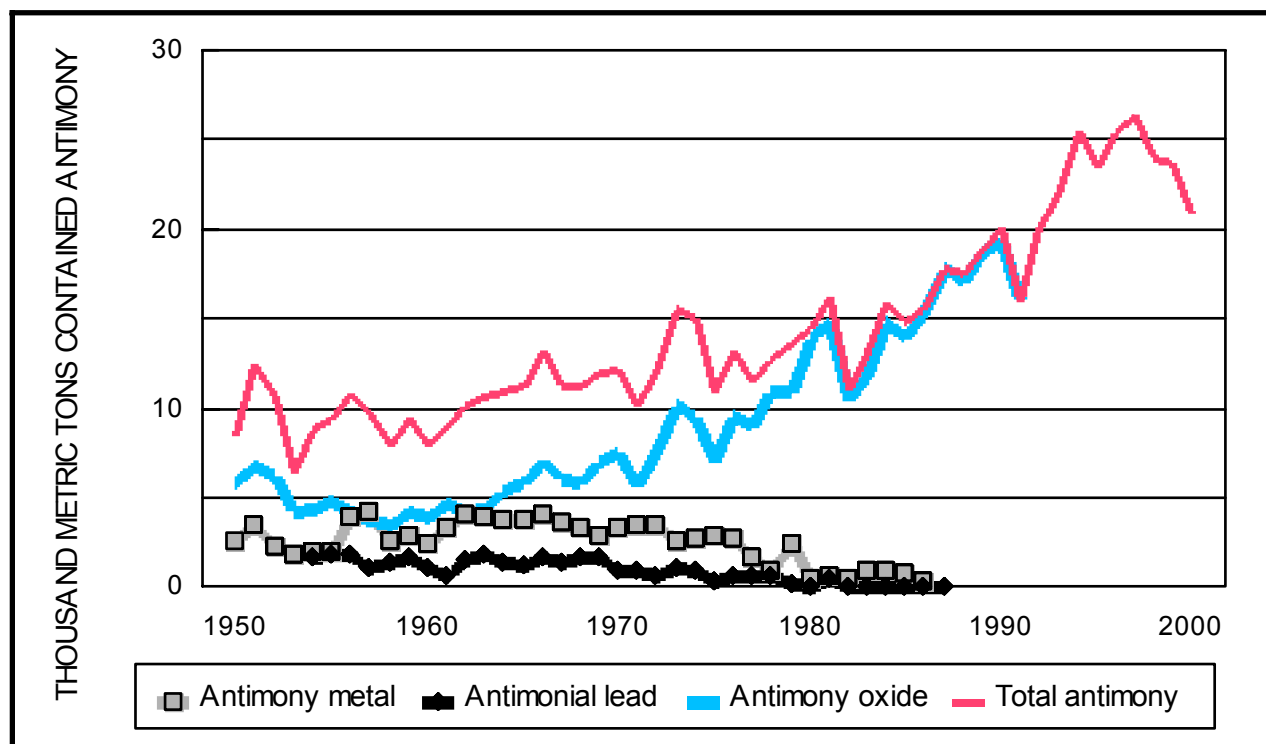

Figure 14: U.S smelter production, primary antimony, 1950-2000. [Data from U.S. Bureau of Mines 1950-95; U.S. Geological Survey, 1996-2001]
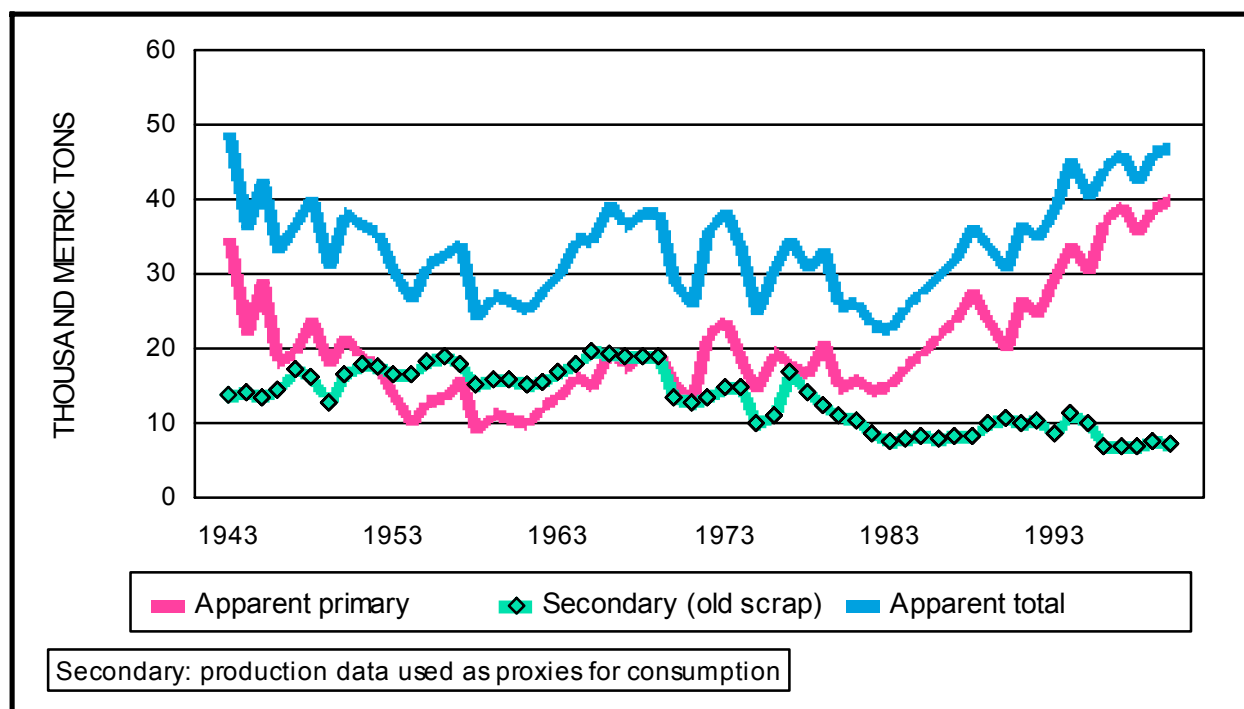
Figure 15: U.S. consumption of antimony, 1943-2000. [Data from U.S. Bureau of Mines 1943-95; U.S. Geological Survey, 1996-2001]

POTENTIAL SUPPLY

As discussed in the section "Sources of antimony," identified world resources of antimony are thought to be in the range of 4 to 6 Mt, and U.S. resources are probably at least 100,000 t. At the levels of mine production (and demand) in 2000, world reserves can supply industrial requirements for about two decades, the reserve base for about three decades, and all identified resources, assuming they can be produced economically, for three to five decades. Should the price of antimony undergo a sustained rise or a sustained fall, the volumes of reserves and reserve base would automatically tend to grow or decrease.

STRATEGIC CONSIDERATIONS

Because the small domestic antimony ore deposits located to date have not been suitable for large-scale production or competitive with the large low-cost foreign deposits, domestic ores have never provided more than a small part of the domestic requirement. To offset the risk of depending largely on foreign sources for its antimony, the U. S. Government has stockpiled antimony for national defense needs for decades. The stockpile target, or goal, has been changed from time to time, which has resulted in either shortfalls or surpluses of stockpiled material, that in turn have prompted periodic purchases or sales of antimony by the Government. In the 1960s, the quantity stockpiled approached 50,000 t; in the 1970s and 1980s, it ran closer to 35,000 t; and by the early 1990s, the level had dropped below 30,000 t. In 1993, the stockpile goal was reduced to zero, and by yearend 2000, the quantity in inventory was down to about 8,300 t, all of which was to be offered for sale during two fiscal years. Although the assessment of vulnerability to loss of foreign supplies has changed, the degree of dependence on imported antimony has increased markedly in the past two decades (fig. 9). U.S. net import reliance for antimony, which is defined as imports minus exports plus adjustments for industry and Government stocks changes, was 94 percent of apparent consumption in 2000, compared with 64 percent in 1990 and 43 percent in 1979.

SUSTAINABILITY OF PRODUCTION AND USE

Because antimony is one of the so-called heavy metals, any activity, such as mining, processing, manufacturing, or end use that may add to the environmental load is of concern. In the United States, more than 80 percent of the

antimony released to the land by all industrial processing and manufacturing activities comes from nonferrous metals smelters. However, difficulties in limiting, but not eliminating, the release of antimony at mines or smelters where adequate environmental regulations are in place do not appear to be insuperable. If such regulations are introduced and enforced worldwide, then antimony's toxicity should not be an impediment to increasing the rate of production to meet the expected larger demand.

The environmental fate of antimony contained in scrapped end products is more problematic. If restrictions on the use of antimony or associated elements, such as the halogens in flame retardants, spread through Europe and then abroad, they will tend to limit the manufacture and international trade of antimony-containing products.

ECONOMIC FACTORS

Known antimony deposits in the United States tend to be small irregular deposits that do not lend themselves to large-scale low-cost mining methods. This, together with the ready availability of ample supplies of foreign antimony, some of which reportedly has been sold at prices below actual production cost in recent years, make it unlikely that any new domestic deposits will be developed in the foreseeable future or that any appreciable funds will be expended in searching for new deposits. This is especially so at the present time, because the annual average price of refined antimony from 1998 through 2000, in constant dollars, was lower than at any other time in the second half of the 20th century. Currently, about 94 percent of the antimony consumed in the United States comes from net imports, and remaining so dependent on outside sources does pose some risk. Antimony, however, is no longer considered to be a critical or strategic material, and acceptable substitutes are available for it in nearly all its uses.

The percentage depletion allowance for domestic antimony mine production is 22 percent. The depletion allowance is a part of the net income derived from mining that is considered to be a return of capital not subject to income tax. Antimony ore, concentrates, metal, and oxides may be imported duty-free. Primary antimony is produced on a small scale domestically. For several years before the sole domestic antimony-producing mine was shut down in early 2001, fewer than 100 mine and smelter workers were engaged in primary antimony production in the United States (Carlin, 2001).

The cost of using antimony in products is probably seldom a factor in deciding whether to use it or substitute for it. It is a minor component of most alloys and other products and is relatively inexpensive so its cost does not limit its consumption. At the same time, because it is usually a minor component of products, the money to be saved by increasing its use at the expense of other metals is negligible.

The economics of recycling of antimony are controlled by the economics of lead recycling. Nearly all antimony scrap consists of lead-based alloys and is recycled at secondary lead smelters. The scrap arises almost entirely from spent LA batteries and is reconstituted as antimonial lead, most of which returns to use in new batteries.

OUTLOOK

The use pattern for primary antimony appears likely to remain relatively stable for the next few years if legislative bans on the use of antimony in plastics do not proliferate too rapidly. Flame retardants are likely to remain the largest use of antimony by far; maintaining market share in the United States and growing at perhaps 4 percent per year worldwide. The use of antimony in catalysts for PET production is forecast to grow at a rapid 10 percent per year worldwide, much slower in the more mature markets, such as the United States, but rapidly in the industrializing countries of the world (Roskill Information Services Ltd., 2001, p. 130-31). Antimony's use in CRT glass for television sets and computer monitors "in the medium-term future" is forecast to rise by 3 percent per year for television and 7 percent per year for computer monitors (Roskill Information Services, 2001, p. 166). The use of antimony in other nonmetallic uses probably will remain static or decline slowly. Overall, consumption for metallic uses is likely to decline, because environmental considerations restrict the use of lead with which metallic antimony is nearly always associated in use.

Resources in the reserve base can provide antimony at the 2000 rate of mine production for about three decades. Secondary antimony recovered for the battery industry can provide most of the metal needed for batteries. Mine production, which is being restrained currently in China, the dominant producer, should be able to expand fast enough to provide for any unexpected growth in consumption.

REFERENCES CITED

Anderson, C.G., 2001, Hydrometallurgically treating antimony-bearing industrial wastes: JOM, v. 53, no. 1, January, p. 18-20.

Berndt, Dietrich, 1997, Maintenance-free batteries—A handbook of battery technology: New York, John Wiley & Sons, 496 p.

Booser, E.R., 1992, Bearing materials, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 4, p. 1-21.

Brown, R.D., 2001, Bismuth, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 1999, v. I, p. 12.1-12.5.

Carlin, J.F., Jr., 1999, Antimony, *in* Plunkert, P.A., and Jones, T.S., comps., Metal prices in the United States through 1998: U.S. Geological Survey, p. 5-6.

Carlin, J.F., Jr., 2001, Antimony: U.S. Geological Survey Mineral Commodity Summaries 2001, p. 20-21.

Carlin, J.F., Jr., 2002, Antimony: U.S. Geological Survey Mineral Industry Surveys 2001 Annual review, 7 p.

East, A.J., and Golden, Michael, 1997, Thermoplastic polyesters, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 19, p. 615-653.

Gann, R.G., 1993, Flame retardants—Overview, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 10, p. 930-936.

Lide, D.R., ed., 1999, Sect. 14, Geophysics, astronomy, and acoustics, in Handbook of chemistry and physics (80th ed.): New York, CRC Press, p. 14-1–14-43..

Li, K.C., 1953, Arsenic and antimony, *in* Mathewson, C.H., ed., Modern uses of nonferrous metals (2d ed.): York, Pennsylvania, The Maple Press, p. 40-53.

Li, T., Archer, G.F., and Carapella, S.C., Jr., 1992, Antimony and antimony alloys, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 3, p. 367-381.

Mesch, K.A., 1993, Heat stabilizers, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 12, p. 1071-1091.

Miller, M.H., 1973, Antimony, *in* Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 45-50.

Moreno, Ann-Marie, ed., 1997, Buyers' guide, *in* Metal traders of the world (6th ed.): London, United Kingdom, Metal Bulletin Books, p. 405-645.

Mote, R.H., 1948, Antimony, *in* Commodity reviews: U.S. Bureau of Mines Minerals Yearbook 1946, part II, p. 128-136.

Plunkert, P.A., 1985, Antimony, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 33-45.

Prengaman, R.D., 1995, Lead alloys, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 15, p. 113-132.

Rabin, Anatol, 1997, Solders and brazing filler metals, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 22, p. 482-497.

Rand, D.A.J., Woods, R., and Dell, R.M., 1998, Batteries for electric vehicles: Taunton, United Kingdom, Research Studies Press, and New York, John Wiley & Sons, 577 p.

Roskill Information Services Ltd., 1997, The economics of antimony (8th ed.): London, United Kingdom, Roskill Information Services Ltd., 184 p., 2 appendixes.

Roskill Information Services Ltd., 2001, The economics of antimony (9th ed.): London, United Kingdom, Roskill Information Services Ltd., 230 p., 2 appendixes.

Schrader, F.C., 1922, Antimony in 1919, *in* Metals: U.S. Geological Survey Mineral Resources of the United States, part I, p. 286-311.

Siegmund, Andreas, and Prengaman, R.D., 2001, Grid alloys for automobile batteries in the new millennum: JOM, v. 53, no. 1, January, p. 38-39.

Touval, Irving, 1993, Antimony and other inorganic flame retardants, *in* Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 10, p. 936-954.

Troitzsch, Juergen, 1990, Flame retarded plastics, *in* International plastics flammability handbook: Munich, Germany, Hanser Gardner Publications, 531 p. (Excerpts containing sections on brominated flame retardants were accessed on the internet September 12, 2000, at URL http://www.firesafety.org/FlameRetardants/FlameRetardants.htm.)

U.S. Agency for Toxic Substances and Disease Registry), September 1995, ToxFAQs for Antimony, accessed October 18, 2000, at URL http://www.atsdr.cdc.gov/tfacts23.html.

U.S. Antimony Corporation, [undated], Montana brand antimony oxide products, accessed March 28, 2000, at URL http://www.usantimony.com/products/ant_oxide.html.

U.S. Bureau of Mines, 1924-31, Antimony: U.S. Bureau of Mines Mineral Resources of the United States, variously paginated.

U.S. Bureau of Mines, 1932-95, Antimony: U.S. Bureau of Mines Minerals Yearbook, variously paginated.

U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

U.S. Environmental Protection Agency, April 12, 2001, Technical fact sheet on antimony, accessed on December 13, 2001, at URL wysiwyg://http:/www.epa.gov/safewater/dwh/t-ioc/antimony.html.

U.S. Geological Survey, 1882-1923, Antimony: U.S. Geological Survey Mineral Resources of the United States, variously paginated.

U.S. Geological Survey, 1996-2001, Antimony: U.S. Geological Survey Minerals Yearbook, variously paginated.

Wang, C.Y., 1952, Antimony—Its geology, metallurgy, industrial uses and economics (3d ed., revised): London, United Kingdom, Chas. Griffin and Co., 170 p.

White, D.E., 1951, Antimony resources of the world, Chap. 3 *in* Materials survey—Antimony: U.S. Bureau of Mines, compiled for National Security Resources Board, p. (III-1)–(III-57).

Wyche, Charlie, 1976, Antimony, *in* Mineral facts and problems: U.S.Bureau of Mines Bulletin 667, p. 79-91.

Suggested sources of information on antimony as a commodity:

U.S. Geological Survey Publications
Antimony, *in* United States Mineral Resources, Professional Paper 820, 1973
Mineral Commodity Summaries, annual
Mineral Industry Surveys, Antimony, annual; also available as Minerals Yearbook, v. I
Mineral Industry Surveys, Antimony, quarterly
Other Publications
American Metal Market, daily
Antimony, *in* U.S. Bureau of Mines Mineral Facts and Problems, 1985
Canadian Mines Handbook, 1998-99
Engineering and Mining Journal, monthly
Metal Bulletin, monthly
Metal Bulletin, weekly
Mining Engineering, monthly
Mining Journal, weekly
Mining Record, weekly
Northern Miner, weekly
Platt's Metals Week, weekly
Randol Mining Directory, 1999
Ryan's Notes, weekly

APPENDIX

Definitions of Reserves, Reserve Base, and Resources

The term "resources," as applied to metals, refers to those concentrations of metal-bearing minerals in the Earth's crust that are currently or potentially amenable to the economic extraction of one or more metals from them. "Reserves" and "reserve base" are subcategories of resources.
"Reserves" refers to the in-place metal content of ores that can be mined and processed at a profit given the metal prices, available technology, and economic conditions that prevail at the time the reserves estimate is made.
"Reserve base" is a more-inclusive term that encompasses not only reserves proper, but marginally economic reserves and a discretionary part of subeconomic resources—"those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics (U.S. Bureau of Mines and U.S. Geological Survey, 1980).