BISMUTH

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Bismuth consumption in the United States increased by about 3% during 2001 compared with that of 2000. Consumption increased in the categories of bismuth alloys and metallurgical additives but decreased in chemicals and pharmaceuticals. In 2001, all primary bismuth consumed in the United States was imported. The only domestic refinery, in Nebraska, produced bismuth as a byproduct of lead refining until July 1997. The last stocks of bismuth held in the National Defense Stockpile (NDS) were sold that same year. The largest foreign producers of refined bismuth were Mexico, China, Peru, and Belgium.

Domestically, about 45% of bismuth was used in bismuth alloys, 36% in pharmaceuticals and chemicals, 17% as metallurgical additives, and 2% for other uses (table 2). Only a small amount of bismuth was obtained by recycling old scrap.

In recent years, several new uses for bismuth have been developed as nontoxic substitutes for lead in various applications. These included the use of bismuth in brass plumbing fixtures, ceramic glazes, crystalware, fishing sinkers, lubricating greases, pigments, and solders. Bismuth was a leading candidate for replacing lead, a toxic metal, in various applications, such as in shot used for waterfowl hunting. Another newly developed use was the improvement of drainage of galvanizing alloys. Poor drainage causes galvanizing alloy to accumulate in corners and angles and to bridge small holes and thin channels, requiring extra cleaning of the workpiece. Although lead additions improve the drainage properties of galvanizing alloys, zinc-bismuth alloys provide the same drainage properties as zinc-lead alloys without the toxicity of lead (Gagne, 2000).

In 2001, the average New York dealer price for bismuth increased slightly from $3.70 per pound to $3.74 per pound (table 1). The annual average price has been fairly steady for the past 3 years; the typical bismuth price cycle consists of long declines followed by fairly steep increases. The value of bismuth consumed domestically in 2001 was about $18.1 million, an increase of 4% compared with that consumed in 2000.

Legislation and Government Programs

The Defense Logistics Agency, which administers the NDS, sold the final 85 metric tons (t) of bismuth in the stockpile on November 4, 1997.

The conversion to plumbing alloys that contain bismuth rather than lead is driven by the Safe Drinking Water Act Amendments of 1996 (Public Law 104-182). This law bans lead from all fixtures, fluxes, pipes, and solders used for the installation or repair of facilities providing water for human consumption (potable drinking water) after August 1998. Increased use of plastic pipe has kept the use of bismuth-alloyed brasses from growing more rapidly.

The U.S. Environmental Protection Agency is enforcing new standards for limiting dangerous levels of lead on painted indoor surfaces, in dust, and on bare soils where children play. These standards provide new and uniform benchmarks for remedial action to safeguard the public from exposure to lead. The standards, which involve Federal agencies and State, local, and tribal governments, are expected to further the use of bismuth as a lead substitute (U.S. Environmental Protection Agency, 2000).

Production

Domestic production of primary bismuth ceased in 1997. Some domestic firms continued to recover secondary bismuth from fusible alloy scrap in 2001, but secondary production data were not available. Secondary production was estimated to be less than 5% of domestic supply during the year.

Consumption

Domestic bismuth use data are collected by the U.S. Geological Survey through a consumption survey. Of the 40 firms that received the consumption survey in 2001, 70% responded. The respondents accounted for an estimated 75% of bismuth consumption in the United States. The amount used by the nonrespondents was estimated on the basis of reports from prior years or on information from other sources.

Bismuth consumption in 2001 was about 2,200 t, a 3% increase from that of 2000 (table 1). Consumption of bismuth in bismuth alloys and in metallurgical additives increased by 10% and 6.6%, respectively, in 2001. Consumption of bismuth in chemical and pharmaceutical uses decreased by 6.5%.

The best known chemical use is that of bismuth subsalicylate, the active ingredient in over-the-counter stomach remedies. Other bismuth pharmaceuticals are used to treat burns, intestinal disorders, and stomach ulcers; veterinary applications are important as well. Bismuth nitrate is the initial material used for the production of most other bismuth compounds. Other bismuth chemical and compound uses include applications ranging from superconductors to some pearlescent pigments in cosmetics and paints.

Bismuth metal is used primarily as a major constituent of various alloys and as a metallurgical additive (table 2). One class of bismuth alloys consists of the fusible (low-melting-point) alloys—combinations of bismuth and other metals, such as cadmium, gallium, indium, lead, and tin. Applications for these alloys included fuel tank safety plugs, holders for lens grinding and other articles for machining or grinding, solders, and fire sprinkler triggering mechanisms.

Bismuth has long been a substitute for the lead added to steel to provide greater machinability. A major domestic steel company began to use a bismuth-containing substitute for the leaded alloy nearly 20 years ago. Bismuth is also added in

small amounts to aluminum and copper alloys to improve machinability. Further, it is added to malleable iron to prevent the formation of graphite flakes. These uses constitute the traditional metallurgical additives category.

There remains considerable interest in bismuth as a nontoxic substitute for lead in several additional applications. Bismuth oxide has been replacing lead oxide in fire assaying precious metals and in ceramic glazes, and bismuth can replace lead as well as steel in shotgun pellets. One market area of steady increase has been the use of bismuth alloy ammunition for waterfowl hunting; the alloy has been 97% bismuth and 3% tin.

Bismuth use in water meters increased in 2001, and bismuth consumption as a metallurgical additive in plumbing alloys also increased during the year. Development of lead-free electronic solders containing bismuth continued in 2001.

Although bismuth has been successful in replacing lead in various applications, it has been challenged as a lead substitute by tungsten and tin (Cusack, 1999).

Prices

The domestic dealer price for commercially pure bismuth, published by Platts Metals Week, averaged about $3.74 per pound in 2001, representing a 1% ($0.04) increase compared with the average for 2000 (table 1). The price was $4.00 per pound at the beginning of 2001, after falling steadily from $4.30 per pound to $3.23 per pound during the first three quarters of 2000 with an increase back to $4.00 per pound late in the year. The price fluctuated near $4.00 per pound for the first quarter of 2001 and then declined below $3.50 per pound during the rest of the year, ending the year at $3.43 per pound. In recent years, bismuth price has cycled between lows of around $3.00 per pound and highs of about $4.00 per pound; this remained true for the year 2001. A major underlying factor for the apparent $4.00 ceiling continued to be the large amount of bismuth normally available from China at lower prices (Mining Journal, 2001b). The price for bismuth was fairly stable during the first quarter of 2001 owing to steady demand for new uses and expected decreases in production worldwide. Steady demand from Japan, Europe, and the United States, lower lead mine production worldwide (bismuth is mainly a byproduct of lead) during the period, and a decline in Peruvian output owing to lower grades of bismuth ore maintained steady prices early in 2001 (Mining Journal, 2001b). These factors outweighed the availability of cheaper imports from China (Metal Bulletin, 2001a). As the first quarter ended, prices remained stable at the higher end of the normal range for bismuth owing to the reluctance of traders to buy until it seemed certain that China would not increase supplies and thereby depress prices (Mining Journal, 2001c).

Later in the year, prices fell in spite of increased demand for new uses, mainly due to a softening in the chemical sector and continued lower price offerings from China. Some buyers delayed purchases, expecting prices to decline even more; however, prices did not continue to fall because Chinese sellers seemed willing to wait for better prices rather than push them lower for immediate sales (Mining Journal, 2001b). Concern over supply also kept prices from falling further as production rates declined in both Mexico and Peru. In addition, Cominco, Ltd., in Canada executed a temporary shutdown of its refinery late in the year (Metal Bulletin, 2001c). Continued pressure from China and the willingness of consumers to lower stocks rather than purchase more bismuth initiated the long price decline in 2001. Buyers seemed ready to use up stocks and wait for prices to fall lower; but they did not decrease further—possibly because China did not have a large excess of supply and because Chinese producers may have been stockpiling materials, waiting for the price to increase again (Metal Bulletin, 2001b; Mining Journal, 2001a).

Support for bismuth price was provided by concern over possible fluctuations in production levels at Doe Run Resources Corp. operations in Peru because Doe Run's parent company, Renco Metals Co., headquartered in New York, filed for chapter 11 bankruptcy in August owing to lack of profits from its other subsidiary, Magnesium Corporation of America. In the past, when bismuth production from Peru decreased, world prices usually increased (Mining Journal, 2001e). China, Mexico, and Peru are the world's largest mine producers of bismuth. They account for about two-thirds of world production, with each country supplying roughly equal amounts.

A balance of all these forces kept the bismuth market fairly stable throughout the year, while the market for most metals was declining, owing to economic uncertainty (Mining Journal, 2001d).

Trade

Total U.S. bismuth imports decreased by nearly 8% by weight in 2001 (table 4). Notable decreases were imports from the United Kingdom, Belgium, and Canada. Exports increased by 10%, with some country-to-country exceptions, but they remained at a much lower total level than imports.

World Review

Bismuth is usually a byproduct of lead or tungsten production. World refinery production of bismuth increased by 5% and, together with large increases in Chinese reserves, eased concern over supply for new uses (table 5). Production was expected to be low in Mexico and Peru but apparently remained stable for both countries.

In Canada, Fortune Minerals, Ltd., in London, Ontario, was seeking partners to develop its NICO deposit in the Northwest Territories. The deposit contains cobalt, bismuth, and gold. According to the company's plan, cobalt and gold would be processed in-house. Bismuth concentrates would be sent to another Canadian company or exported for processing. The project is expected to supply 1,000 metric tons per year of bismuth over a period of 15 years (Fortune Minerals, 2001).

In Denmark, a ban prohibiting lead in several products where it can be replaced took effect during 2001. The ban is intended to reduce lead consumption by one-third in the next few years (Mining Journal, 2000).

Spain has banned the use of lead ammunition for hunting and shooting matches. In recent years, lead poisoning has killed about 40,000 birds in Spain, annually. Ammunition makers could use bismuth to replace lead in this application (Metal Bulletin, 2001§[1]).

[1]References that include a section twist (§) are found in the Interent References Cited section.

In the United Kingdom, two new bismuth alloys have been developed as materials for chucks designed to hold irregularly shaped workpieces for machining, etc. The new alloys melt at 137° C and 220° C. They do not shrink on solidification and consequently provide an excellent grip as long as needed. After the chuck is used, it can be remelted and used again (Metallurgia, 2001). This use of bismuth provides most of the metal that is recycled. If recycled in the same plant where the chuck is used, the bismuth would be considered new scrap; when sent to another plant for recycling, the metal would be old scrap.

Current Research and Technology

A bismuth-strontium-calcium-copper-oxide superconducting ceramic is the heart of a power transmission system being installed in inner-city Detroit where space is not available to expand the existing electrical infrastructure. Three high temperature superconductor (HTS) cables will replace nine conventional copper cables. The HTS cables will weigh only 900 pounds compared with 25,000 pounds for the conventional cables. The new cables allow more power transmission while using less space. The bismuth-containing ceramic compound is encased in silver and then drawn out to a thin wire. The silver forms a protective barrier for the naturally brittle superconductor and allows oxygen to diffuse through to the ceramic core. By carrying more electricity in a smaller space with practically no losses due to electrical resistance, HTS systems are expected to help avoid blackouts and brownouts caused by power shortages (Guerriere, 2001).

The use of bismuth oxide additions in electronic ceramics has increased, especially in Japan. The additions enhance the electronic properties of ferrites and ceramic capacitors (Roskill's Letter from Japan, 2001).

Scientists at Cardiff University in the United Kingdom, supported by Japan's New Energy and Industrial Technology Development Organization, have developed a new coevaporation process for depositing both p-type and n-type bismuth telluride thin films. Both types are needed to pair up in a thermoelectric device. Coevaporation is simpler and cheaper than other methods for making the thin films, e.g., sputtering, chemical vapor deposition, molecular beam epitaxy, etc. This is the first time that p-type bismuth telluride films have been made using coevaporation. Microcoolers made from these materials could be used for dissipating heat generated by integrated circuits or devices on a circuit board, stabilizing the temperature of solid-state lasers, cooling infrared detectors, and for improving thermal conditions in many other applications (Advanced Coatings & Surface Technology, 2001).

More than 100,000 t of steel have been successfully galvanized using a new galvanizing alloy containing bismuth. This alloy is the conventional zinc-nickel alloy used for reactive steels with the addition of 1.8% tin and 0.5% bismuth. The higher fluidity and wetability of the new galvanizing alloy results in lower consumption of zinc, better surface appearance, less dross, and less finishing required after galvanizing (Smith, 2001). The same results are obtained with a new zinc-bismuth alloy (no nickel) used for ordinary steels. Traditionally, lead additions have been used to produce similar results. The new bismuth alloys, however, yield matching or better results with out the toxicity of lead.

A book providing a comprehensive survey of recent research on lead-free solders was published in 2001. In addition to the bismuth-tin binary system, the book describes ternary and quaternary combinations where bismuth is one of the components. One chapter focuses exclusively on the role of bismuth in lead-free solder (Hwang, 2001).

Bismuth ammunition may be the answer to the quandary of law enforcement and safety in close quarters and such problem areas as inside an airliner or near a nuclear, biological, or chemical plant. Bismuth bullets have the same lethal power, accuracy, and ballistic properties as lead, but they disintegrate into fine powder when they strike a substantial solid surface, such as an airliner fuselage, concrete floor, or metal target. Consequently, bismuth bullets could be the ideal material for sky marshals to use inside aircraft, for shooting ranges, and for law enforcement or military training (Wilcox, 2001§).

In February 2002, the Bismuth Institute was dissolved. For nearly 30 years the Institute provided statistics and encouraged bismuth research and development as well as new uses for the metal. It was instrumental in sustaining bismuth's market as a medicinal after a crisis in France owing to excessive self-medication by individuals. It helped to gain worldwide recognition for the significance of bismuth in China, now the world's leader in reserves and in production of the metal. It actively promoted the new uses now coming onstream and consistently reminded potential users of the environmental benefits of bismuth (Metal Bulletin, 2002).

Outlook

The long-range outlook for bismuth indicates that demand will probably grow, especially in new applications and as the development of nontoxic bismuth substitutes for lead continues. The use of bismuth in plumbing fixtures and bird shot ammunition is still increasing in the United States and in Europe. Although partial bans on lead for these uses have been announced in Denmark and Spain, the increase in substitution for lead in such markets elsewhere has been slow because the applicable environmental regulations are less stringent (Roskill's Letter from Japan, 2001).

A significant near term increase in bismuth supply as a lead byproduct is unlikely because total world production of lead will remain relatively stable and an increasing fraction of lead demand will be satisfied by recycling. Nevertheless, a global shortage of bismuth is not anticipated. In China, where bismuth is a byproduct of tungsten processing, new technologies applied to this resource have increased world bismuth reserves (Werner and others, 1998, p. 54). Therefore, despite any large increases in world demand, Chinese supplies can be expected to help keep the bismuth market stable (Mining Journal, 2001b).

It appears that low prices, due to the nearly constant availability of Chinese bismuth and the general deflationary trend for metals during the past decade, are the limiting factor for bismuth supply. Usually, more bismuth appears in the market whenever prices increase. Thus, it appears that the limiting factor for bismuth supply is low prices, not the availability of the metal (Camak, 1999). As new uses increase in market size, growing demand may cause prices to rise. Because Chinese producers could increase production to meet any anticipated increase in demand, stability in prices will require careful management of supplies.

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TABLE 1
SALIENT BISMUTH STATISTICS 1/

(Metric tons)

	1997	1998	1999	2000	2001
United States:					
Consumption	1,530	1,990	2,050	2,130	2,200
Exports 2/	206	245	257	491	541
Imports for consumption	2,170	2,720	2,110	2,410	2,220
Price, average, domestic dealer, per pound	$3.50	$3.60	$3.85	$3.70	$3.74
Stocks, December 31, consumer	213	175	121	118	95
World:					
Mine production (metal content) 3/	4,360 r/	3,870 r/	54,500 r/	3,620 r/	4,000 e/
Refinery production 3/	4,070	4,040	3,360	3,790 r/	3,990 e/

e/ Estimated. r/ Revised.
1/ Data are rounded to no more than three significant digits.
2/ Comprises bismuth metal and the bismuth content of alloys and waste and scrap.
3/ Excludes the United States.

TABLE 2
BISMUTH METAL CONSUMED IN THE UNITED STATES, BY USE 1/

(Metric tons)

Use	2000	2001
Chemicals 2/	861	805
Bismuth alloys	889	981
Metallurgical additives	346	369
Other	34	45
Total	2,130	2,200

1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.

TABLE 3
U.S. EXPORTS OF BISMUTH METAL, ALLOYS, AND WASTE AND SCRAP, BY COUNTRY 1/

Country	2000 Quantity (kilograms, metal content)	2000 Value (thousands)	2001 Quantity (kilograms, metal content)	2001 Value (thousands)
Australia	--	--	306	$7
Belgium	819	$13	194,000	1,110
Canada	84,900	806	89,700	669
China	--	--	11,100	14
Dominican Republic	2,570	140	2,380	70
France	87	9	--	--
Germany	151,000	1,910	90,300	486
Honduras	14,600	184	--	--
Hong Kong	912	109	101	24
Israel	--	--	1,000	3
Japan	5	6	--	--
Korea, Republic of	33,700	59	--	--
Malaysia	5,930	58	--	--
Mexico	99,100	875	91,100	745
Netherlands	21,100	61	36,600	135
Norway	20	6	--	--
Peru	--	--	872	10
Philippines	--	--	2,070	6
Russia	4,750	60	4,760	62
Singapore	276	12	260	14
Taiwan	510	10	--	--
Trinidad and Tobago	13,100	74	--	--
United Kingdom	56,300	432	12,600	94
Venezuela	1,330	19	4,250	52
Total	491,000	4,840	541,000	3,500

-- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF METALLIC BISMUTH, BY COUNTRY 1/

Country	2000 Quantity (kilograms)	2000 Value (thousands)	2001 Quantity (kilograms)	2001 Value (thousands)
Bahamas, The	5,400	$11	--	--
Belgium	832,000	6,870	728,000	$6,150
Canada	120,000	829	42,500	287
China	426,000	3,290	501,000	3,610
Demark	--	--	52	59
Finland	1	3	--	--
France	--	--	2,820	32
Germany	56,600	475	57,800	424
Italy	--	--	506	17
Japan	6,830	347	6,950	302
Korea, Republic of	14	4	--	--
Mexico	516,000	3,940	605,000	4,430
Netherlands	409	10	1,160	24
Peru	20,400	155	--	--
Spain	420	5	34,000	1,330
United Kingdom	430,000	3,180	241,000	1,790
Total	2,410,000	19,100	2,220,000	18,400

-- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 5
BISMUTH: WORLD MINE AND REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country	Mine					Refinery				
	1997	1998	1999	2000	2001 e/	1997	1998	1999	2000	2001 e/
Belgium e/	--	--	--	--	--	800	700	700	700	700
Bolivia	684	941	709 e/	6 r/	5	55	44	57	14 r/	15
Bulgaria e/	40	40	40	40	40	40	40	40	40	40
Canada 3/	196	219	311	202	200	--	--	--	--	--
China e/	550	240	2,680	1,120 r/	1,500	760	820	860	770 r/	850
Italy e/	--	--	--	--	--	5	5	5	5	5
Japan 4/	30 r/ e/	24 r/ e/	24 r/ e/	26 r/ e/	28	550	479	481	518	550
Kazakhstan e/	115	115	130	130	130	50	50	55	55	130
Mexico 5/	1,642	1,204	548	1,000 e/	1,000	990	1,030	412	900 e/	900
Peru	1,000 e/	1,000 e/	1,000 e/	1,000 e/	1,000	774	832	705	744	750
Romania e/	40	40	40	40	40	35	35	35	35	35
Russia e/	50	35	50	50	50	10	7	10	10	10
Serbia and Montenegro e/	5	5	2	2	2	(6/)	(6/)	--	--	--
Tajikistan e/	5	5	5	5	5	--	--	--	--	--
United States	W	W	W	W	W	W	--	--	--	--
Total	4,360 r/	3,870 r/	5,540 r/	3,620 r/	4,000	4,070	4,040	3,360	3,790 r/	3,990

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

1/ World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

2/ Table includes data available through April 6, 2002. Bismuth is produced primarily as a byproduct of other metals, mostly lead; Bolivia is the sole producer of primary bismuth.

3/ Figures listed under mine output are the metal content of concentrates produced.

4/ Mine output figures have been estimated to be 5% of reported metal output figures.

5/ Refined metal includes bismuth content of imported smelter products.

6/ Less than 500 kilograms. Production in kilograms: 1997--20 and 1998--430 (reported).