Bismuth

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Bismuth consumption in the United States increased more than 5% during 2002, compared with 2001. Consumption increased in all major categories—bismuth alloys; metallurgical additives; and chemicals, cosmetics, and pharmaceuticals. In 2002, all primary bismuth consumed in the United States was imported. Bismuth was last produced domestically, as a byproduct of lead refining, at a Nebraska refinery that closed in 1997. The last stocks of bismuth held in the National Defense Stockpile (NDS) were sold that same year. In 2002, the largest foreign producers of refined bismuth were Mexico, China, Peru, and Belgium. The Belgian producer, however, only refined bismuth from imported concentrates.

Domestically, about 46% of bismuth was used in bismuth alloys; 35%, 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 a nontoxic substitute for lead. These included the use of bismuth in brass plumbing fixtures, fire assaying, ceramic glazes, crystal ware, fishing weights, shot for waterfowl hunting, lubricating greases, pigments, and solders. Another newly developed use, as a substitute for lead, is for improving the drainage characteristics of galvanizing alloys. Poor drainage results in the accumulation of galvanizing alloy in corners and angles and the bridging of small holes and narrow channels—thus requiring extra cleaning of the work piece. Although lead additions also 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 2002, the average annual New York, NY, dealer price for bismuth decreased drastically from $3.74 per pound to $3.14 per pound (table 1). The average annual price had been fairly steady from 1999 through 2001 with the typical bismuth price cycle consisting of long declines followed by fairly steep increases. Bismuth prices in 2002 never recovered from a long decline in the first half of the year. The value of bismuth consumed domestically in 2002 was about $16.1 million. Thus, although consumption in 2002 increased by almost 6% compared to the prior year, the value of the bismuth consumed decreased by almost 13% compared with the value consumed in 2001.

In February, the Bismuth Institute, headquartered in Brussels, Belgium, discontinued operations and ceased to exit after almost 30 years of service. The Institute had provided bismuth statistics and encouraged research and development as well as new uses for the metal. It had helped open trade with China, now the leader in world bismuth reserves and production. By late 2002, the Bismuth Producers Association (BiPA) had been formed and had taken over many of the Institute's former roles. The founding members of BiPA are Cía. Doe Run Perú, Met-Mex Peñoles, S.A., C.V. (Mexico), and Sidech, S.A. (Belgium); Hunan Shizhyuan Nonferrous Metals Co., Ltd. (China) subsequently joined the new organization.

Legislation and Government Programs

The Defense Logistics Agency, which administers the NDS, sold the last remaining bismuth in the stockpile in 1997.

In anticipation of a European Union ruling that would ban lead in solders by 2006, Japan's Matsushita Electric Industrial Co. began production of lead-free solders based on alloys of tin, silver, bismuth, and indium (Metal-Pages, 2002d§[1]). Subsequently, trade organizations in the European Union, Japan, and North America announced agreements to eliminate lead solder from manufacturing processes by 2005 (Metal-Pages, 2002c§). Many Japanese manufacturers already are lead-free in their soldering applications. NEC Corporation has used lead-free solder on their personal computer motherboards since 1999, and Pioneer Corporation converted to lead-free solders in September 2002.

The Safe Drinking Water Act Amendments of 1996 (Public Law 104-182) has banned lead from all fixtures, fluxes, pipes, and solders used for the installation or repair of facilities providing potable drinking water since 1998. The ban prompted a conversion to plumbing alloys that contain bismuth rather than lead. Increased use of plastic pipe, however, has kept the use of bismuth-alloyed brasses from growing more rapidly in plumbing applications.

The U.S. Environmental Protection Agency (EPA) in coordination with industry began preparing life cycle studies of lead-free solders in anticipation of pending restrictions on lead-containing solders in Europe and Japan. Industry experts believe U.S. industry must respond to these impending restrictions in a competitive and timely manner, identifying viable alternatives to traditional lead-tin solders or risk losing as much as $240 billion in revenues during a 3-year period. One of the lead-free solder alternatives being considered contains 3.3% bismuth (U.S. Environmental Protection Agency, 2002§).

In parallel, a study was begun in 2002 by the European Union, Japan, and the Republic of Korea to develop system solutions for advanced and sustainable lead-free soldering. The next generation environment-friendly soldering technology (EFSOT) study has been initiated to investigate lead-free soldering technologies with respect to providing analyses of biological impact, environmental effects, and recycling criteria. The European portion of this study is planned for completion in September 2005 (EFSOT, 2003§).

The EPA has begun to enforce new standards limiting dangerous levels of lead on painted indoor surfaces, in dust,

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

and on bare soils where children play. The standards provide uniform benchmarks for remedial action to safeguard the public from exposure to lead. These standards 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 2002, but secondary production data were not available. Secondary production was estimated to be less than 5% of domestic supply during the year.

Consumption

The U.S. Geological Survey surveys domestic bismuth consumption annually. The amount used by the nonrespondents is estimated on the basis of reports from prior years or on information from other sources.

Bismuth consumption in 2002 was about 2,320 metric tons (t), a 5% increase from that of 2001 (table 1). Consumption of bismuth in bismuth alloys showed a strong increase of about 9% in 2002 compared with 2001. Consumption of bismuth in chemical and pharmaceutical uses increased only slightly, by less than 1%; while consumption in metallurgical additives showed a moderate increase of 5%.

Although it has the crystal structure of a semimetal, bismuth is often considered a metal. This crystal structure, along with several of its other salient properties makes it an ideal substitute for lead in extreme-pressure additives. These unique salient properties include expansion on solidification, widest range between melting and boiling points, lowest thermal and heat conductivity and the most diamagnetic of all metals, least toxic of known metals, and lowest absorption for neutrons; bismuth is also characterized as "soft," like lead (Rohr, 2000).

Bismuth pharmaceuticals include the well-known bismuth subsalicylate, the active ingredient in over-the-counter stomach remedies and other bismuth medicinal compounds used to treat burns, intestinal disorders, and stomach ulcers of humans and animals. Bismuth nitrate is the initial material used for the production of most bismuth compounds. Other applications of bismuth chemicals and compounds include uses in superconductors and pearlescent pigments for 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 with other metals, such as cadmium, gallium, indium, lead, and tin. Applications for these alloys include fuel tank safety plugs, holders for lens grinding and other articles for machining or grinding, solders, and fire sprinkler-triggering mechanisms.

In addition to the lead-free solder noted above, 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. 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). 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.

Prices

The domestic dealer price for commercially pure bismuth, published by Platts Metals Week, averaged about \$3.14 per pound in 2002, representing a 16% (\$0.60) decrease, compared with the average for 2001 (table 1). The New York dealer price for commercially pure bismuth, according to Platts Metals Week, was \$3.43 per pound at the beginning of 2002 and declined steadily through February to reach \$3.20 per pound and then began to climb, attaining \$3.45 per pound at the end of the first quarter. By the end of the second quarter, the price had declined to \$3.30 per pound. The beginning of the third quarter saw a sharp decline in the price of the metal as it dropped by 10 to 15 cents per pound. This was followed by a 4-month stabilization into November when the price again dropped by about 5 cents per pound, then ended the year in the range of \$2.70 per pound to \$3.10 per pound.

The decline of Chinese bismuth prices in the first quarter was offset by steady demand and the loss of production at the Guangzhou bismuth smelter when its owner declared bankruptcy and halted operations. Approximately 40 t was removed from the world market when Teck Cominco Ltd. (Canada) temporarily closed its Trail smelter in British Columbia, Canada. Additional bismuth metal has become available, when the Antamina mine in Peru added a concentrator circuit designed to separate a molybdenum-bismuth concentrate. Met-Mex Peñoles suffered flooding at its Bismarck Mine in the northern State of Chihuahua, but this was not anticipated to affect future bismuth supplies.

Trade

Total U.S. bismuth imports decreased 13.1% by weight in 2002 compared with the prior year's figures (table 4). Notable decreases were seen in imports from China, Germany, Mexico, Spain, and the United Kingdom. These were offset to a minor extent by increases in imports from Canada and Peru.

Bismuth exports decreased drastically, with 2001 levels more than four times those of 2002. Notable decreases were seen in exports to Belgium, Canada, China, Germany, Mexico, and the Netherlands. These were only slightly offset by increases in exports to Malaysia, Peru, and the United Kingdom (table 3).

World Review

Throughout most of the world, bismuth is a byproduct of processing lead ores; in China, it is a byproduct of tungsten ore processing. The Tasna mine in Bolivia, the only mine that produced bismuth from a bismuth ore, has been on standby since the mid-1990s awaiting a significant rise in the metal price.

World refinery production of bismuth increases of almost 3% in 2002 (table 1), together with a large increase in Chinese reserves, eased concern regarding future supply for new uses (table 5). Although some of the smaller producers reduced their output of bismuth metal, Hunan Shizhyuan Nonferrous Metals, China's largest producer, maintained its production of 600 t, or 86% of capacity, and others have been producing at capacity based on contracted sales (Metal-Pages, 2002a, b; Platts Metals Week, 2002).

Several bismuth-containing deposits are in varying stages of mining feasibility review. Verena Minerals Corp. (Canada) has a gold project in Brazil's Rio Grande do Norte State with the second phase of exploration now underway. Gold and tungsten values have been announced, and bismuth values will be included at the feasibility stage (Verena Minerals Corporation, 2003§).

In Canada, Fortune Minerals Ltd. of London, Ontario, announced the results of a preliminary assessment of its recently discovered NICO cobalt-gold-bismuth deposit near Yellowknife, Northwest Territories. This prefeasibility assessment has shown encouraging results based on initial metallurgical testing, an initial mine plan (which includes underground and surface mine development), and in-house resource modeling (Fortune Minerals Ltd., 2003§).

Tiberon Minerals Ltd., also of Canada, has released the results of a prefeasibility study on its 70%-owned Nui Phao polymetallic deposit in Vietnam. These results have been encouraging for development of a mine expected to produce 3.5 million metric tons per year of ore with an average production of 360 metric tons per year (t/yr) of bismuth in concentrate (Tiberon Minerals Ltd., 2003§).

In spite of the poor performance of the electronics sector and a 29% drop in domestic demand registered the previous year, estimated bismuth production in Japan rose slightly in 2002 as the level of lead refining remained stable (Roskill's Letter from Japan, 2002). In addition, trade data indicated an increase in bismuth imports during the year. After 10 years of averaging 300 t/yr, imports rose to 480 t, of which only 66 kilograms was imported from the United States. A large portion of these imports in 2002 is believed to be for solders and alloys, products for which Japan appears to be the world leader in efforts to become lead-free (Metal-Pages, 2003§).

Current Research and Technology

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).

Bismuth accounts for 2.5% to 3.2% of new heat-treatable aluminum-silicon alloys used in casting and forging. Advanced Casting Technologies Inc. (MI), which developed these alloys, expects them to improve fluidity, eliminate soldering to the die, and reduce shrinkage (Advanced Materials and Processes, 2002).

AlphaMed Inc. (MA) made its first generator shipments of radium-224, which decays to lead-212 and bismuth-212. The production is funded by a grant from the U.S. Department of Energy to privatize production of this isotope. The byproduct bismuth isotope is an alpha-emitting radioisotope that is used for research in radioimmunotherapy with important applications for the treatment of cancer (AlphaMed Inc., 2002§).

Scientists have developed a new method for using an optical fiber sensor comprised of a single block bismuth germanate crystal to measure current and voltage simultaneously. The polarized light from the crystal is split into two beams. One is used to measure current based on the Faraday effect and the other is used to measure voltage based on the Pockels effect. This sensor is simpler and less expensive than existing optical sensors allowing measurement of electric power (Li and Yoshino, 2002).

Hewlett-Packard Company is investigating an option to use bismuth for developing lead-free printed circuit board assemblies (Henshall and Lindsley, 2001). Their strategy centers on the investigation of lead-silver-copper solders, tin-bismuth-silver solders, and other potential alternatives. The advantages of the tin-bismuth-silver alloy for solders are increased overall product reliability due to lower processing temperatures, reduced package failure due to delamination and cracking during processing, material cost reduction due to lower temperature rating on printed circuit board components, reduced scrap due to printed circuit assembly failures during manufacture, and compatibility with a variety of lead-free printed circuit board surface finishes, component surface finishes, and ball grid array solder compositions.

The disadvantages of the tin-bismuth solder include greater brittleness and lower resistance to thermal fatigue under shock, vibration, or handling compared with tin-lead solders. The tin-bismuth solders may also be more difficult to form wire for rework. Worldwide bismuth capacity is limited and might not be sufficient to supply wave soldering needs, especially since bismuth is currently obtained largely as a byproduct of lead mining. Finally, if not adopted as an industry standard solder, the tin-bismuth-silver solution likely will be costly.

A substitute for bismuth in superconducting tape has been developed at Los Alamos National Laboratory's Superconductivity Technology Center. The new nickel alloy tape is coated with fine layers of oriented zirconia, with subsequent layers of nickel to create a superconducting film as thin as six microns. This new tape can carry one million amperes per square centimeter of current, or about 14 times the capacity of the bismuth-based tape and 200 times that of copper wire. It is expected that transformers, electric motors, transmission cable, and other products will incorporate the new tape within 2 years (Herrera, 2001).

Bismuth ammunition is a possible solution to law enforcement and safety problems concerning firearm use on airliners, or near nuclear, biological, and chemical plants. 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 barrier. Consequently, bismuth bullets could be the ideal ammunition for sky marshals and pilots to use inside aircraft and for security patrols at hazardous materials plants (Wilcox, 2001§).

Outlook

The outlook for bismuth indicates that demand will probably continue to grow this decade. Demand for bismuth in the steel sector, although relatively minor compared to other use sectors, appears to be rising. The chemical sector is increasingly turning to bismuth as Japan increases its use as a replacement for lead in pigments (Mining Journal, 2003).

International agreements to eliminate lead from solder in manufacturing processes by 2005 in Europe, Japan, and North America will tend to increase the demand for bismuth during the next several years. Many Japanese manufacturers have become lead-free in some or all of their soldering applications and studies on how best to develop lead-free solders are being performed by the European Union, the Republic of Korea, Japan, and the United States, independently.

The major new applications for bismuth in the near future appear to be the following: 1) yellow pigments for automobile and plastics applications; 2) lead-free solders, where know-how is currently being developed, as discussed earlier (EFSOT and EPA studies); 3) free-cutting brasses in Japan; 4) glass frit for electro-conductive glass in automobiles; 5) soft ferrites for magnets and magnetic tapes; 6) electronic ceramics; and 7) thermoelectric applications where bismuth-selenium and bismuth-tellurium alloys are used to create heat or cold packs, especially in marine applications (Yves Palmieri, Bismuth Producers' Association, oral commun., April 3, 2003).

A significant near term increase in supplies of lead byproduct bismuth 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, 2001).

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, constrain bismuth supply. Usually, more bismuth appears quickly 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 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)

		1998	1999	2000	2001	2002
United States:						
Consumption		1,990	2,050	2,130	2,200	2,320
Exports[2]		245	257	491	541	131
Imports for consumption		2,720	2,110	2,410	2,220	1,930
Price, average, domestic dealer	dollars per pound	3.60	3.85	3.70	3.74	3.14
Stocks, December 31, consumer		175	121	118	95	111
World:						
Mine production, metal content[3]		3,930 r	5,490 r	3,800 r	4,270 r	4,070 e
Refinery production		4,330 r	3,610 r	4,220 r	5,050 r	5,190 e

eEstimated. rRevised.

[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 CONSUMED IN THE UNITED STATES, BY USE[1]

(Metric tons)

Use	2001	2002
Chemicals[2]	805	813
Bismuth alloys	981	1,070
Metallurgical additives	369	388
Other	45	50
Total	2,200	2,320

[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	2001 Quantity (kilograms of metal content)	2001 Value (thousands)	2002 Quantity (kilograms of metal content)	2002 Value (thousands)
Australia	306	$7	--	--
Belgium	194,000	1,110	759	$7
Brazil	--	--	999	8
Canada	89,700	669	47,700	458
China	11,100	14	3,000	60
Dominican Republic	2,380	70	500	35
Germany	90,300	486	6	5
Hong Kong	101	24	332	54
Israel	1,000	3	167	22
Japan	--	--	66	26
Korea, Republic of	--	--	4	6
Malaysia	--	--	9,520	165
Mexico	91,100	745	34,800	247
Netherlands	36,600	135	5,990	42
Peru	872	10	4,000	50
Philippines	2,070	6	--	--
Russia	4,760	62	2,070	25
Singapore	260	14	150	6
United Arab Emirates	--	--	58	5
United Kingdom	12,600	94	20,600	98
Venezuela	4,250	52	--	--
Total	541,000	3,500	131,000	1,320

-- 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 METALIC BISMUTH, BY COUNTRY[1]

Country	2001 Quantity (kilograms)	2001 Value (thousands)	2002 Quantity (kilograms)	2002 Value (thousands)
Bahamas, The	--	--	684	$6
Belgium	728,000	$6,150	724,000	5,160
Canada	42,500	287	49,800	328
China	501,000	3,610	393,000	1,760
Denmark	52	59	--	--
France	2,820	32	--	--
Germany	57,800	424	835	30
Hong Kong	--	--	58,500	346
Italy	506	17	208	8
Japan	6,950	302	3,150	152
Mexico	605,000	4,430	518,000	3,090
Netherlands	1,160	24	102	28
Peru	--	--	19,500	121
Spain	34,000	1,330	--	--
United Kingdom	241,000	1,790	163,000	1,150
Total	2,220,000	18,400	1,930,000	12,200

-- 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 1998	Mine 1999	Mine 2000	Mine 2001	Mine 2002[e]	Refinery 1998	Refinery 1999	Refinery 2000	Refinery 2001	Refinery 2002[e]
Belgium[e]	--	--	--	--	--	700	700	700	700	1,000
Bolivia	1,032 r	708 r	75 r	60 r	70	83 r	57	6 r	66 r	60
Bulgaria[e]	40	40	40	40	40	40	40	40	40	40
Canada[3]	186 r	264 r	202	258 r	189 [4]	250 r, e	250 r, e	250 r, e	250 r, e	250
China[e]	240	2,680	1,120	1,250 r	1,300	820	860	770	1,230 r	1,250
Italy[e]	--	--	--	--	--	5	5	5	5	5
Japan[e, 5]	24	24	26	28	28	479 [4]	481 [4]	518 [4]	550	560
Kazakhstan[e]	115	130	130	150 r	150	50	55	55	130	130
Mexico	1,204 [6]	548 [6]	1,112 r, 6	1,390 r, 6	1,200	1,030	412	1,083 r	1,390 r	1,200
Peru	1,000 e	1,000 e	1,000 e	1,000 e	1,000	832	705	744	640 r	650
Romania[e]	40	40	40	40	40	35	35	35	35	35
Russia[e]	35	50	50	50	50	7	10	10	10	10
Serbia and Montenegro[e]	5	2	2	2	2	(7)	--	--	--	--
Tajikistan	5	5	5	5	--	--	--	--	--	--
United States	W	W	W	W	W	--	--	--	--	--
Total	3,930 r	5,490 r	3,800 r	4,270 r	4,070	4,330 r	3,610 r	4,220 r	5,050 r	5,190

[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 4, 2003. Bismuth is produced primarily as a byproduct of other metals, mainly lead and tungsten.

[3]Figures listed under mine output are the metal content of concentrates produced, according to Natural Resources Canada, 2001-2002.

[4]Reported figure.

[5]Mine output figures have been estimated to be 5% of reported metal output figures.

[6]Refined metal plus bismuth content of impure smelter products.

[7]430 kilograms (reported).