# 2005 Minerals Yearbook

## SULFUR

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# SULFUR

## By Joyce A. Ober

**Domestic survey data and tables were prepared by Brian W. Jaskula, statistical assistant, and the world production table was prepared by Glenn J. Wallace, international data coordinator.**

In 2005, for the first time since production was reported in the United States in 1938, recovered sulfur output was significantly lower than it was in 2004. Two devastating hurricanes struck the Gulf Coast region of the United States in August and September, resulting in major refinery shutdowns in Louisiana and Texas; the net effect of the hurricanes was a 6.1% decrease in sulfur recovered from refineries for the year. Sulfur recovered from natural gas operations was down by 9.1% compared with 2004 because of the natural depletion of the sulfur content of natural gas deposits and the successful implementation of an acid-gas reinjection project in Wyoming. Total elemental sulfur production was 6.7% lower than it was in 2004. The reduced recovery from natural gas had been anticipated, but the unanticipated weather-related outages caused significant disruptions in the market.

Even with the unexpectedly low production, the United States was once again the world's leading sulfur producer in 2005 with total production of 9.5 million metric tons (Mt) of sulfur in all forms. All elemental sulfur and byproduct sulfuric acid was produced as a result of efforts to meet environmental requirements that limit atmospheric emissions of sulfur dioxide. Worldwide, compliance with environmental regulations contributed to increased sulfur recovery, although the decreased production in the United States affected output globally. Estimated worldwide production of native sulfur was slightly higher. In the few countries where pyrites remain an important raw material for sulfuric acid production, sulfur production from pyrites increased by 5.5%.

Production continued to outpace sulfur demand, which resulted in increased stocks at some operations, especially at a few in remote locations from which it is difficult and costly to ship the product to market. There was some remelting at more market-accessible stockpiles to meet strong global demand, and the net increase in sulfur stocks was relatively low.

Through its major derivative, sulfuric acid, sulfur ranks as one of the most important elements used as an industrial raw material and is of prime importance to every sector of the world's fertilizer and manufacturing industries. Sulfuric acid production is the major end use for sulfur, and consumption of sulfuric acid has been regarded as one of the best indices of a nation's industrial development. More sulfuric acid is produced in the United States every year than any other inorganic chemical; 37.2 Mt, which is equivalent to about 12.1 Mt of elemental sulfur, was produced in 2005, slightly more than that of 2004 (U.S. Census Bureau, 2006).

In 2005, all salient U.S. sulfur statistics were lower than the corresponding data in 2004. Domestic production and shipments of sulfur in all forms were, respectively, 6.5% and 7.0% lower than those of 2004. Consumption decreased slightly, and exports, imports, prices, stocks, and values were lower (table 1; figures 1-4).

Estimated world sulfur production was the same in 2005 as it was in 2004. Recovered elemental sulfur is produced primarily during the processing of natural gas and crude petroleum. For the past 4 years, an average of 90% of the world's sulfur production came from recovered sources. Some sources of byproduct sulfur are unspecified, which means that the material could be elemental or byproduct sulfuric acid. The quantity of sulfur produced from recovered sources was dependent on the world demand for fuels, nonferrous metals, and petroleum products, rather than for sulfur.

World sulfur consumption was slightly higher than it was in 2004; about 50% was used in fertilizer production, and the remainder, in myriad other industrial uses. World trade of elemental sulfur increased by 7.0% from the levels recorded in 2004. Worldwide inventories of elemental sulfur were relatively unchanged.

### Legislation and Government Programs

The U.S. Environmental Protection Agency (EPA) moved the retail compliance date for availability of ultralow sulfur diesel (ULSD) from September 1, 2006, to October 15, 2006, in order to give retailers more time to comply with the 15-part-per-million (ppm) requirement. During this time, 22-ppm diesel will be allowed to be marketed as ULSD to ensure a smooth transition to the lower standard. The EPA will conduct a study to determine if the 2-ppm testing tolerance is adequate (Sulphur, 2005l). Preparations for implementation of the new sulfur requirements for on-road diesel were well underway to meet the October 2006 deadline (Sulphur, 2005c).

The EPA has proposed rules for lower sulfur content in fuels for small marine engines, such as those used in small ships and ferries, and auxiliary engines for larger ships used for electrical power while in port. The proposal limited sulfur content to 0.05% by 2007 and 15-ppm by 2012. The EPA was considering limits for larger vessels that were 30% lower than the sulfur content allowed by the International Maritime Organization's (MARPOL) ratified revised Sea Pollution Prevention Law Annex VI for ships in open oceans and 0.1% sulfur content for fuels burned in port (Sulphur, 2005p).

Another market area that might be addressed soon by regulators is home heating oil. Marketers and regulators began discussions on the possibility of decreasing the sulfur content from the current level of 2,500-ppm to the 15-ppm required for highway diesel beginning in 2006. Although very early in the deliberation process, availability of sufficient supply was the largest concern if new requirements were established close on the heels of prior reductions (Goldstein, 2005).

## Production

***Recovered Elemental Sulfur.***—U.S. production statistics were collected on a monthly basis and published in the U.S. Geological Survey (USGS) monthly sulfur Mineral Industry Surveys. All of the 107 operations to which survey requests were sent responded; this represented 100% of the total production listed in table 1. In 2005, production and shipments were 6.7% and 7.3% lower than those of 2004, respectively. The value of shipments was 11.6% lower than that in 2004 owing to lower production and decreased average domestic unit value of elemental sulfur. Trends in sulfur production are shown in figures 1 and 3.

The decreased production from petroleum refineries was caused by Hurricanes Katrina and Rita. These storms, which made landfall in the U.S. Gulf Coast area on August 29 and September 24, 2005, respectively, led to decreased sulfur production as a result of precautionary measures taken at oil refineries to prepare for the hurricanes and downtime to repair damage caused by the storms. A total of 28 petroleum refineries were affected to varying degrees by the hurricanes. A few reduced production in preparation for the arrival of either or both storms but quickly resumed full capacity when it became apparent that those facilities were out of danger. Other refineries experienced brief but complete shutdowns as the storms passed. Several refineries were damaged by the storms and remained closed until power was restored and repairs were made (U.S. Department of Energy, 2005§[1]).

As of December 31, all but three of these refineries were operating, most at full capacity. Two refineries were seriously damaged by Hurricane Katrina and remained closed into 2006. ConocoPhillips Co. restarted its Alliance refinery at the end of January 2006, and Murphy Oil Corp. restarted its Meraux refinery in May 2006 (ConocoPhillips Co., 2006, p. 6; Murphy Oil Corp., 2006, p. 21). BP p.l.c.'s Texas City, TX, refinery, the third largest refinery in the United States, was closed in late September 2005 and was not expected to reopen in 2006. Although the refinery was closed in preparation for Hurricane Rita, the extensive repairs were only partially as a result of the storm. The company took advantage of the shutdown to implement extensive maintenance and repairs that were determined necessary during inspections and studies earlier in the year (BP America Inc., 2006§). Total production lost as a result of the hurricanes was estimated to be about 300,000 metric tons (t) (North American Sulphur Review, 2005d).

Recovered elemental sulfur, which is a nondiscretionary byproduct from petroleum-refining, natural-gas-processing, and coking plants, was produced primarily to comply with environmental regulations that were applicable directly to emissions from the processing facility or indirectly by restricting the sulfur content of the fuels sold or used by the facility. Recovered sulfur was produced by 42 companies at 106 plants in 26 States and 1 plant in the U.S. Virgin Islands. The size of the sulfur recovery operations varied greatly from plants producing more than 500,000 metric tons per year (t/yr) to others producing less than 500 t/yr. Of all the sulfur producers canvassed, 35 produced more than 100,000 t of elemental sulfur in 2005, 15 produced between 50,000 and 100,000 t, 36 between 10,000 and 50,000 t, 17 between 1,000 and 10,000 t, and 4 plants produced less than 1,000 t. By source, 79.3% of recovered elemental sulfur production came from petroleum refineries or satellite plants that treated refinery gases and coking plants; the remainder was produced at natural-gas treatment plants (table 3).

The leading producers of recovered sulfur, all with more than 500,000 t of sulfur production, in descending order of production, were Exxon Mobil Corp., Valero Energy Corp., ConocoPhillips, BP, Chevron Corp., Shell Oil Co. (including its joint ventures with Petróleos Mexicanos, S.A. de C.V. and Saudi Refining Inc. and subsidiary operations), CITGO Petroleum Corp. (including the joint-venture refinery it owned with Lyondell Chemical Co.), and Burlington Resources Inc. The 60 plants owned by these companies accounted for 65.4% of recovered sulfur output during the year. Recovered sulfur production by State and district is listed in tables 2 and 3.

Mergers and acquisitions of oil and gas companies that also recover sulfur at their operations resulted in some leading sulfur producers becoming more dominant in 2005. ChevronTexaco Corp., the second ranked oil and gas company in the United States, acquired ninth ranked Unocal Corp. The company later changed its name to Chevron Corp. (Clark, J.R., 2005). Marathon Petroleum Co. LLC adopted its new name after it bought Ashland Inc.'s share of the two companies' joint venture Marathon Ashland Petroleum LLC to become the sole owner of seven refineries in the United States (Nakamura, 2005). Valero acquired Premcor Refining Group Inc. to make it the leading refiner in the United States and the fifth ranked in the world with 18 refineries and crude capacity of 3.3 million barrels per day (Oil & Gas Journal, 2005d). In December, ConocoPhillips announced a proposal to acquire Burlington Resources. ConocoPhillips sulfur production came primarily from oil refining, and Burlington Resources was a major natural gas producer. The transaction was expected to be completed in 2006 (Oil & Gas Journal, 2005a).

Five of the largest refineries in the world are in the United States. The largest U.S. refineries, in decreasing order of capacity, are owned by ExxonMobil in Baytown, TX, and Baton Rouge, LA; Hovensa L.L.C. [(a joint venture of Hess Corp. and Petróleos de Venezuela S.A. (PdVSA)] in St. Croix, VI; BP in Texas City, TX; and CITGO (a wholly owned subsidiary of PdVSA) in Lake Charles, LA (Nakamura, 2005). The capacity to process large quantities of crude oil does not necessarily mean that refineries recover large quantities of sulfur, but all of these refineries were major producers of refinery sulfur. Sulfur production depends on installed sulfur recovery capacity as well as the types of crude oil that are refined at the specific refineries. Major refineries that process low-sulfur crudes may have relatively low sulfur production. According to a survey conducted by Oil & Gas Journal, U.S. refining capacity represents 20.4% of global capacity, but installed sulfur recovery capacity at U.S. oil refineries, which is reported to be 43,700 metric tons per day (t/d) and equivalent to nearly 16 million metric tons per year (Mt/yr); represents 65% of total

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

world refinery capacity for sulfur recovery (Stell, 2005§). A survey published by British Sulphur Publishing reported that 14 oil refining companies were in the process of or had recently completed installation of sulfur recovery equipment at 26 refineries in the United States. If all the new sulfur recovery units were operated at full capacity, production of recovered sulfur from those operations could increase by nearly 2.6 Mt/yr (Sulphur, 2005n). Although the hurricanes caused unexpected decreased sulfur recovery in 2005, during the past 10 years, the sulfur content of crude petroleum processes at U.S. refineries has increased owing to increased crude oil imports that typically have higher sulfur content than domestic crudes. This was a major contributing factor to increased sulfur recovery trends from refineries (Swain, 2005).

***Byproduct Sulfuric Acid.***—Sulfuric acid production at copper, lead, molybdenum, and zinc roasters and smelters accounted for about 7.5% of the total domestic production of sulfur in all forms and totaled 711,000 t; this was a decrease of 3.8% compared with that of 2004 (table 4). Three acid plants operated in conjunction with copper smelters, and four were accessories to lead, molybdenum, and zinc smelting and roasting operations. The three largest sulfuric acid plants were associated with copper mines and accounted for 80.9% of the output. The copper producers—ASARCO LLC, Kennecott Utah Copper Corp., and Phelps Dodge Corp.—each operated a sulfuric acid plant at its primary copper smelter. Kennecott's smelter in Salt Lake City, UT, was shut down for extended periods during the year for maintenance, contributing to reduced production of byproduct sulfuric acid (North American Sulphur Review, 2005b).

In December, Korea Zinc Co. announced that it would close its zinc smelter in Sauget, IL, in February 2006. Although announced as an indefinite closure, it was likely to be permanent, removing 140,000 t/yr of acid from the market, which is equivalent to about 46,000 t/yr of sulfur (North American Sulphur Review, 2005c).

## Consumption

Apparent domestic consumption of sulfur in all forms was 3.4% lower than that of 2004 (table 5). Reduced consumption was a result of supply constraints created by the hurricanes, but the decrease was not as significant as the production decline because expanded imports compensated for some of the production shortfall. In addition, the hurricanes had an adverse impact on some of the facilities that normally consume sulfur in the Gulf Coast region, reducing demand in the area. Of the sulfur consumed, 70.0% was obtained from domestic sources—elemental sulfur (65.2%) and byproduct acid (4.9%)—compared with 71.5% in 2004 and 73.3% in 2003. The remaining 30.0% was supplied by imports of recovered elemental sulfur (22.9%) and sulfuric acid (7.1%). The USGS collected end-use data on sulfur and sulfuric acid according to the standard industrial classification of industrial activities (table 6).

Sulfur differs from most other major mineral commodities in that its primary use is as a chemical reagent rather than as a component of a finished product. This use generally requires that it be converted to an intermediate chemical product prior to its initial use by industry. The leading sulfur end use, sulfuric acid, represented 63.1% of reported consumption with an identified end use, and it is reasonable to assume that nearly all of the sulfur consumption reportedly used in petroleum refining was first converted to sulfuric acid, bringing sulfur used in sulfuric acid to 87.9% of the total. Some identified sulfur end uses were included in the "Unidentified" category because these data were proprietary. Data collected from companies that did not identify shipment by end use also were tabulated as "Unidentified." A significant portion of the sulfur in the "Unidentified" category may have been shipped to sulfuric acid producers or exported, although data to support such assumptions were not available.

Because of its desirable properties, sulfuric acid retained its position as the most universally used mineral acid and the most produced and consumed inorganic chemical, by volume. Data based on USGS surveys of sulfur and sulfuric acid producers showed that reported U.S. consumption of sulfur in sulfuric acid (100% basis) increased by 4.7%, and total reported sulfur production decreased slightly. Reported consumption figures do not correlate with calculated apparent consumption owing to reporting errors and possible double counting in some data categories. These data are considered independently from apparent consumption as an indication of market shares rather than actual consumption totals.

Agriculture was the leading sulfur-consuming industry; consumption decreased to 9.05 Mt compared with 9.11 Mt in 2004, but as a percentage of total consumption, agricultural use of sulfur increased to 62.2% from 61.4%. Reported consumption of sulfur in the production of phosphatic fertilizers was slightly higher than that of 2004, but reported consumption of sulfur used in other agricultural chemicals, including sulfur fertilizers, decreased by 8.8%. According to export data from the U.S. Census Bureau (2006), the estimated quantity of sulfur needed to manufacture exported phosphatic fertilizers increased by 9.8% to 3.6 Mt.

The second ranked end use for sulfur was in petroleum refining and other petroleum and coal products. Producers of sulfur and sulfuric acid reported a 13.0% decrease in the consumption of sulfur in that end use. Demand for sulfuric acid in copper ore leaching, which was the third ranked end use, decreased by 12.6% because production of electrowon copper decreased.

The U.S. Census Bureau (2006) also reported that 2.5 Mt of sulfuric acid was produced as a result of recycling spent and contaminated acid from petroleum alkylation and other processes. Two types of companies recycle this material—companies that produce acid for consumption in their own operations and also recycle their own spent acid and companies that provide acid regeneration services to sulfuric acid users. The petroleum refining industry was believed to be the leading source and consumer of recycled acid for use in its alkylation process.

## Stocks

Yearend inventories held by recovered elemental sulfur producers decreased to 160,000 t, 13.5% less than those of

2004 (table 1). Based on apparent consumption of all forms of sulfur, combined yearend stocks amounted to less than a 5-day supply compared with a 5-day supply in 2004, a 6-day supply in 2003, a 6-day supply in 2002, and an 8-day supply in 2001. Final stocks in 2005 represented 2.8% of the quantity held in inventories at the end of 1976 when sulfur stocks peaked at 5.65 Mt, a 7.4-month supply at that time (Shelton, 1978, p. 1296).

Two companies were installing sulfur-forming, storage, and ship-loading facilities to expand their options for sulfur sales to overseas markets. Much of the sulfur production on the West Coast is formed and shipped overseas, but Gulf Coast producers have been limited to U.S. markets because they have only been able to ship molten sulfur. Gulf Sulphur Services Ltd. was building a facility in Faustina, LA, with a forming capacity of 4,000 t/d. Martin Midstream Partners L.P. was installing equipment capable of forming of 2,000 t/d of sulfur prills at its Neches facility in Beaumont, TX (Sulphur, 2005g).

## Prices

The contract prices for elemental sulfur at terminals in Tampa, FL, which are reported weekly in Green Markets, began the year at $61.50 to $64.50 per metric ton. In September, prices increased to $66.50 to $69.50 per ton and increased again in November to $73.00 to $76.00 per ton and remained at that level through the remainder of the year. The price increases in the fall were a direct result of the reduced sulfur production at refineries that were shut down and damaged during the hurricanes.

Based on total shipments and value reported to the USGS, the average value of shipments for all elemental sulfur was estimated to be $30.92 per ton, which was 5.2% lower than that of 2004. Prices vary greatly on a regional basis, which caused the price discrepancies between Green Markets and USGS data. Tampa prices were usually the highest reported in the United States because of the large sulfur demand in the central Florida area. During most of 2005, U.S. west coast prices were listed at $24 to $27 per ton, higher values than what producers have obtained for many years. Nearly all the sulfur produced in this region is processed at forming plants, incurring substantial costs to make solid sulfur in acceptable forms that can be shipped overseas. The majority of west coast sulfur was shipped overseas. Global sulfur prices generally were higher than domestic prices in 2005.

## Foreign Trade

Exports of elemental sulfur from the United States, which included the U.S. Virgin Islands, were 27.9% lower in quantity than those of 2004 but only 12.7% lower in value because the average unit value of export material increased to $80.74 per ton (table 7). Exports from the west coast were 405,000 t, or 59.2% of total U.S. exports. Exports from the U.S. Virgin Islands were 103,000 t, or 15.1% of the U.S. total.

The United States continued to be a net importer of sulfur. Imports of elemental sulfur exceeded exports by more than 2.1 Mt. Recovered elemental sulfur from Canada, Mexico, and Venezuela delivered to United States terminals and consumers in the liquid phase furnished 99.5% of all U.S. sulfur import requirements. Total elemental sulfur imports were slightly lower in quantity, and lower prices for imported material resulted in the value being 8.2% lower than it was in 2004. Imports from Canada, mostly by rail, were slightly lower in quantity, waterborne shipments from Mexico were 21.7% lower than those of 2004, and waterborne imports from Venezuela were estimated to increase by a factor of five and account for about 14.5% of all imported elemental sulfur (table 9).

In addition to elemental sulfur, the United States also had significant trade in sulfuric acid. Sulfuric acid exports were 65.4% higher than those of 2004 (table 8). Acid imports were 7.9 times those of exports (tables 8, 10). Canada and Mexico were the sources of 89.6% of United States acid imports, most of which were probably byproduct acid from smelters. Canadian and some Mexican shipments to the United States came by rail, and the remainder of imports came primarily by ship from Chile and Europe. The tonnage of sulfuric acid imports was 11.7% more that of 2004, and the value of imported sulfuric acid increased by 17.4%.

## World Industry Structure

The global sulfur industry remained divided into two sectors—discretionary and nondiscretionary. In the discretionary sector, the mining of sulfur or pyrites is the sole objective; this voluntary production of native sulfur or pyrites is based on the orderly mining of discrete deposits with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the nondiscretionary sector, sulfur or sulfuric acid is recovered as an involuntary byproduct; the quantity of output subject to demand for the primary product irrespective of sulfur demand. Discretionary sources, once the primary sources of sulfur in all forms, represented 10.5% of the sulfur produced in all forms worldwide in 2005 (table 11).

Poland was the only country that produced more than 500,000 t of native sulfur by using either the Frasch or conventional mining methods (table 11). Frasch process is the term for hot-water mining of native sulfur associated with the caprock of salt domes and in sedimentary deposits; in this mining method, the native sulfur is melted underground with superheated water and brought to the surface by compressed air. Small quantities of native sulfur were produced in Asia, Europe, and South America. The importance of pyrites to the world sulfur supply has significantly decreased; China and Finland were the only countries of the top producers whose primary sulfur source was pyrites. About 80.0% of pyrite world production was in China, and 7.0%, in Finland.

Of the 25 countries listed in table 11 that produced more than 500,000 t of sulfur, 18 obtained the majority of their production as recovered elemental sulfur. These 25 countries produced 92.9% of the total sulfur produced worldwide. The international sulfur trade was dominated, in descending order by quantity, by Canada, Russia, Saudi Arabia, the United Arab Emirates, Japan, and Iran; these countries exported more than 1 Mt of elemental sulfur each and accounted for more than 70% of total sulfur trade. Major sulfur importers, in descending order, were China, Morocco, the United States, India, Brazil, and Tunisia, all with imports of more than 1 Mt.

World production of sulfur was the same in 2005 as it was in 2004; consumption was believed to be slightly higher than in 2004, but less than production, making 2005 the 14th consecutive year that sulfur production exceeded consumption.

Prices in most of the world were believed to have averaged higher throughout the year than in the previous year, for the third consecutive year. Native sulfur production, including production of Frasch sulfur at Poland's last operating mine, was slightly higher than that of 2004. Recovered elemental sulfur production was slightly lower mostly as a result of the curtailments in the United States, and byproduct sulfuric acid production increased by 3.9% compared with that of 2004. Supplies of sulfur in all forms continued to exceed demand; worldwide sulfur inventories increased slightly, much of which was stockpiled in Canada and Kazakhstan, although Canadian stocks actually declined owing to the strong international demand for sulfur. Globally, production of sulfur from pyrites was 5.4% higher.

According to a survey conducted by Oil & Gas Journal, worldwide refining capacity increased by 3.3% in 2005, although the number of refineries decreased by 2.1%. The largest increases were in Asia and the Middle East, followed by North America, Western Europe, and South America. Refining capacity increases in Eastern Europe were lower, and in Africa, capacity remained level. No regions experienced declines. All increases were a result of expansions at existing refineries; no new refineries began production in 2005. The capacities of the refineries that closed in 2005 were relatively small (Nakamura, 2005).

As the sulfur content of diesel and other fuels decreases, sulfur production from refining increases. Regulations reducing the allowable sulfur content of diesel fuel were being phased in around the world to varying degrees and varying timeframes, but none later than 2010. Europe and Australia have mandated a sulfur content of 10 ppm or less. The United States and Canada require an upper limit of 15-ppm, and the Republic of Korea has set the limit at 30-ppm. China, India, and South Africa have established different standards by regions, some at 50-ppm, others at 350-ppm, and others at 500-ppm. Standards in Latin America range from 50 to 5,000-ppm (Tippee, 2005).

The European Parliament enacted new rules for marine fuels that were to be phased in beginning in May 2006. The sulfur content limit for marine fuels has been reduced to 1.7% (from an average of 2.7% previously) for all ships in the Baltic Sea effective May 19, 2006, and for ships in the North Sea and the English Channel starting in fall 2007. Passenger vessels with regular routes between European ports must meet the earlier deadline, and ships operating on inland waterways and berthed in European Union (EU) ports will be restricted to fuels containing 0.1% sulfur starting January 1, 2010. These changes were expected to reduce sulfur dioxide emissions from ships by 500,000 t/yr. Results will be evaluated in 2008, and depending on the results, more restrictions may then be imposed if the emission reductions are not satisfactory or if the United Nations' Maritime Organization has been successful in implementing reduced sulfur provisions. Between 1990 and 2000, sulfur dioxide from land-based sources in the EU decreased by 60% and was expected to decrease to 20% to 25% of 1990 levels by 2010. Emissions from seagoing ships have increased by 30% (Sulphur, 2005p).

## World Review

***Canada.***—Canada was second only to the United States in production of byproduct sulfur and sulfur in all forms, although total production declined by 5.6% in 2005. The majority of sulfur production came from natural gas plants in Alberta at which production declined, as did recovery at oil sands operations because of a fire at one plant that curtailed production there. Canada led the world in exports of elemental sulfur and stockpiled material. Canadian offshore exports were 6.1 Mt, 3.4% below those of 2004, much of it going to China. For the third consecutive year, strong demand prompted remelting of stocks in Canada, resulting in a decrease of 1 Mt (North American Sulphur Review, 2006). At yearend, Canadian stocks were estimated to be 12 Mt. Much of the remaining stockpiled sulfur is in northern Alberta, from where transportation is difficult and expensive (D'Aquin, 2005).

Alberta has huge deposits of oil sands with estimated reserves of 300 billion barrels of recoverable crude oil that contain 4% to 5% sulfur (Stevens, 1998). The crude oil resource in oil sands in Alberta is larger than the proven reserves of crude oil in Saudi Arabia. As traditional petroleum production in Canada has declined, oil sands have become a more important source of petroleum for the North American market (Pok, 2002, p. 3). Because the bitumen recovered at the oil sands deposits is high-density, high-sulfur petroleum, it must be upgraded to higher quality products or refineries must be adapted to process this type of raw material. Oil sands operations in Alberta continued to expand, including a proposal to increase Suncor Energy, Inc.'s capabilities with the addition of another upgrader, additional sulfur recovery capacity, and increased bitumen supply (Sulphur, 2005o).

***China.***—China was the world's leading producer of pyrites with 52.0% of sulfur in all forms coming from that source. The country is also the leading sulfur importer. China has become the leading sulfuric acid producer in the world, with 40 Mt in 2004 (the last year for which data is available), an increase of 18.5% from that in 2003. Sulfuric acid production has increased from all sources, but elemental sulfur-base production has increased at a faster rate than pyrites or smelting. Increasing demand for sulfuric acid for the phosphate fertilizer industry in China was expected to drive sulfuric acid production to 53 Mt in 2010, with 48% sulfur-base, 30% from pyrites, and 21% from smelter acid. Recovered sulfur production, still relatively low in China, was 827,000 t in 2004, but was expected to approach 2 Mt in 2010 (Cunningham, 2005).

Environmental regulations in China were beginning to address the air-quality issues faced in that country. Sulfur dioxide emissions from coal-fired powerplants were expected to reach nearly 20 Mt in 2005. The Government of China developed a plan to reduce emissions at 31 of the country's largest coal burners (Sulphur, 2005j). A new metallurgical coke plant was engineered to include desulfurization and sulfur recovery technology. Although the sulfur recovery will be relatively low at about 20 t/d (7,300 t/yr), this type of development is an indicator of increased environmental awareness in China (Sulphur, 2005m).

***Iran.***—Increased recovery of associated gas (natural gas found in crude petroleum deposits either dissolved in the oil or trapped as free gas above the oil) in Iran will result in addition sulfur production and exports. The Amak Project in southern Iran that has the capacity to recover 180 t/d of elemental sulfur was completed in September (Sulphur, 2005e). The fourth and fifth phases of development of the South Pars gasfield off the coast of Iran were completed and began production of natural gas, gas condensate, and 400 t/d of sulfur. The gasfield, which is to be developed in 24 phases, is thought to contain more than 8% of the world's gas reserves and more than 50% of Iran's (Sulphur, 2005q).

Sulfur exports from Iran were 650,000 t in 2004 but are expected to increase significantly with the completion of additional phases at the South Pars gasfield that have a combined capacity of 600 t/d (219,000 t/yr) along with 400,000 t/yr of additional export material from the Khangiran gasfield. (Cunningham, 2005).

***Poland.***—The single remaining Frasch sulfur mine operating in the world is the Osiek Mine in Poland that opened in 1993. Reserves at Osiek were estimated to be 36 Mt with production capacity of 800,000 t/yr. Most of the production was exported to Morocco for use in phosphate fertilizer production (King, 2005).

***Qatar.***—Qatar Liquefied Gas Company Ltd. (Qatargas) operated a liquefied natural gas (LNG) plant in Ras Laffan Industrial City fed by the offshore North Field, the world's largest nonassociated natural gas field. Qatargas produced 450 t/d (164,000 t/yr) of granulated sulfur in 2005, but plans for huge expansions in LNG production will result in additional sulfur production, eventually expected to reach 12,000 t/d (4.4 Mt/yr). No reinjection of acid gases was planned at this project (Cunningham, 2005).

***Russia.***—Russia's Astrakhangazprom, LLC was the world's leading sulfur producing company. It produced sulfur at the Astrakhan gas processing plant from eight sulfur recovery plants each with the capacity to produce about 80 metric tons per hour. Recent sulfur developments at Astrakhan have focused on improving the quality of the product through installation of forming equipment to minimize the sales of crushed and broken sulfur, replacing it with pelletized sulfur with a low acidity level (Sulphur, 2005b).

***Saudi Arabia.***—Sulfur recovery was expected to increase dramatically in Saudi Arabia in the next few years. Sulfur recovery units planned for gas processing plants were expected to have the capacity to recover nearly 3 Mt/yr of elemental sulfur. An example of such an operation is the Khursaniyah gas plant that was being developed to process the natural gas from the Abu Hadriya, Fadhili, and Khursaniyah oilfields near Jubail. Development of these oilfields was expected to result in the production of large quantities of crude oil, natural gas, ethane, natural gas liquids, and 1,800 t/d (657,000 t/yr) of elemental sulfur (Oil & Gas Journal, 2005c; Sulphur, 2005h).

Saudi Arabian Oil Co. planned to build a refinery in Yanbu to supply international markets, possibly with investments from Indian refiners. Lack of capacity in India for refining high-sulfur crude oils has been a major factor in increased energy costs in recent years. Indian participation will relieve some of the pressure in India for low-sulfur fuel supplies. Other international markets could include the United States east coast, Europe, and other parts of Asia. Sulfur will be recovered at the refinery (Sulphur, 2005a).

Although much of the additional sulfur produced at these operations will be exported, a new project was under development that was expected to consume domestic sulfur in Saudi Arabia. A large phosphate fertilizer project was planned that could consume more than 4,000 t/d (1.46 Mt/yr) of sulfur to produce the sulfuric acid required (Cunningham, 2005).

***United Arab Emirates.***—Activities were in progress to increase sulfur recovery and handling in the United Arab Emirates by 2007. The sulfur recovery capacity at Abu Dhabi Gas Industries' Habshan Gas Complex was to be expanded with the installation of two sulfur recovery units with the combined capacity of 1,600 t/d (580,000 t/yr). Abu Dhabi Oil Refining Co. planned to expand its terminal at Ruwais by installing granulation capacity, expanding liquid and solid sulfur storage facilities, replacing existing granulation units, constructing truck unloading stations, and building a new export jetty. Construction was expected to take about 21 months (Middle East Economic Digest, 2005; Sulphur, 2005d).

***Venezuela.***—Sulfur recovery capacity in operation or under construction at heavy oil upgraders in Venezuela was almost 1 Mt/yr in 2005, most of which was exported. Additional projects to increase petroleum production from the Orinoco Belt have the potential of increasing sulfur production by a factor of five or more. PdVSA announced plans to build three refineries in Barinas, Caripito, and Cabruta, all of which will process heavy high-sulfur crude petroleum from the Orinoco Belt. During the refining, an additional 500,000 t of elemental sulfur is likely to be recovered (North American Sulphur Review, 2005b). Political issues, however, may limit foreign involvement in these projects. The Organic Hydrocarbons Law, enacted in 2002, requires more than 50% Government control of projects involving foreign companies. The law raised the highest royalty to 30% from a previous high of 16.7%. Joint-venture ownership rules have limited the lifetime of the agreements to 25 years, down from 35 years for the first agreements, although these terms may be renegotiated. The early agreements for developing heavy-oil upgraders were more attractive to foreign investors. The more restrictive law may make it uneconomic for foreign investors to participate in future projects (Sulphur, 2005k).

PdVSA has warned that foreign companies that do not agree to new terms for their Venezuela ventures risked total takeover by the Venezuelan company. The new agreements would give PdVSA 60% to 80% interests with 25-year partnerships in projects in which the foreign companies are already involved (Sulphur, 2005f). In addition, officials in Venezuela were considering the sale of PdVSA's United States subsidiary CITGO because the company did not represent a significant benefit to the people of Venezuela (North American Sulphur Review, 2005a).

## Current Research and Technology

One common method for stockpiling excess sulfur is in blocks, where molten sulfur is poured into forms, which then cool to form large solid masses of elemental sulfur. Sulfur can be emitted in several ways from these blocks when left exposed to the atmosphere. Small, but significant quantities of sulfuric acid result from microbial activity and rainfall. Very small quantities of hydrogen sulfide and sulfur dioxide may be released from the surfaces of freshly poured sulfur blocks. Weathered blocks are a source of wind-blown sulfur dust, and in very hot conditions, sulfur can sublime into the atmosphere, becoming part of the global sulfur cycle.

Alberta Sulfur Research Ltd. (ASR) proposed a very simple method to minimize these emissions. The proposed method entailed covering the horizontal surfaces of sulfur blocks with golf-ball-sized pieces of limestone or broken concrete to reflect sunlight, keeping surface temperatures lower to minimize sublimation, protecting the surface from weathering, and neutralizing any sulfuric acid that might form. ASR also determined that the addition of a surfactant to molten sulfur reduces cracking when it solidifies, limiting the effects of moisture on the block (Clark, Peter, 2005).

## Outlook

Although sulfur production was lower in 2005, the industry was expected to resume its trends toward increased production, slow growth in consumption, higher stocks, and expanded world trade. U.S. production from petroleum refineries was expected to recover quickly to pre-2005 levels and increase substantially in the next few years as expansions, upgrades, and new facilities at existing refineries are completed. The expansions were enabling refiners to increase throughput of crude oil and to process higher sulfur crudes; additional sulfur production will be a byproduct of refining upgrades. Production from natural gas operations is expected to be substantially lower in 2006 as a result of declines in production, especially from Wyoming, the source of 72.0% of all domestic gas-derived sulfur recovery. Sulfur recovered from natural gas could decrease up to 450,000 t/yr owing to the successful implementation of a reinjection project at ExxonMobil's Wyoming plant (D'Aquin, 2005). The reinjection process increased gas inlet capacity, and reduced carbon dioxide venting, sulfur dioxide emissions, and sulfur handling costs. The old sulfur recovery unit had high operating expenses and maintenance costs (Oil & Gas Journal, 2005b). Depletion at other fields as a natural function of long-term extraction of natural gas is likely to result in a further decrease of 100,000 t/yr from that source (D'Aquin, 2005). Burlington Resources recently expanded its operation in Wyoming but had the option of storing excess production underground if the markets were not favorable for sales. Theoretically, this material would be available to meet future needs. In reality, however, it was more likely to represent an option for disposing of unwanted surplus material.

Worldwide recovered sulfur output is expected to increase significantly in the future. For the next 2 or 3 years, sulfur supply and demand is expected to be reasonably well balanced. Severe sulfur surpluses, however, are expected beginning in 2010 with acceleration thereafter as a result of increased production, especially from oil sands in Canada, natural gas in the Middle East, expanded oil and gas operations in Kazakhstan, and Venezuela's heavy-oil processors (Sulphur, 2005i).

Additional increases will come from Russia's growth in sulfur recovery from natural gas and Asia's improved sulfur recovery at oil refineries. Refineries in developing countries should begin to improve environmental protection measures and, in the future, eventually approach the environmental standards of plants in Japan, North America, and Western Europe.

The world demand for natural gas is expected to maintain strong growth, and sulfur recovery from that sector will continue to increase. Future gas production, however, is likely to come from deeper, hotter, and more sour deposits that will result in even more excess sulfur production unless more efforts are made to develop new large-scale uses for sulfur. Other alternative technologies for reinjection and long-term storage to eliminate some of the excess sulfur supply will require further investigation to handle the quantity of surplus material anticipated (Hyne, 2000).

Byproduct sulfuric acid production will remain relatively steady in the United States as long as the copper smelters remain idle or no additional smelters close. With the copper industry's switch to lower cost production processes and producing regions, the idle smelters may never reopen.

Worldwide, the outlook is different. Because copper production costs in some countries are lower than in the United States, acid production from those countries has increased, and continued increases are likely. Many copper producers have installed more efficient sulfuric acid plants to limit sulfur dioxide emissions at new and existing smelters. Byproduct sulfuric acid production is expected to increase to 70.3 Mt in 2014 from about 47 Mt in 2005. Worldwide, sulfur emissions at nonferrous smelters have declined as a result of improved sulfur recovery; increased byproduct acid production is likely to become more a function of metal demand than a function of improved recovery technology. One-half of the projected increase of byproduct acid production will likely be from smelters in China, with additional quantities from Chile and Peru, although production from all regions was expected to increase (Sulphur, 2005i).

Frasch sulfur and pyrites production, however, have little chance of significant long-term increases, although higher sulfur prices have resulted in temporary increases in pyrites production and consumption. Because of the continued growth of elemental sulfur recovery for environmental reasons rather than demand, discretionary sulfur has become increasingly less important as demonstrated by the decline of the Frasch sulfur industry. The Frasch process has become the high-cost process for sulfur production. Pyrites, with significant direct production costs, is an even higher cost raw material for sulfuric acid production when the environmental aspects are considered. Discretionary sulfur output should show a steady decline. The decreases will be pronounced when large operations are closed outright for economic reasons, as was the case in 2000 and 2001.

Sulfur and sulfuric acid will continue to be important in agricultural and industrial applications, although consumption will be less than production. Because sulfuric acid consumption for phosphate fertilizer production was expected to increase at a lower rate than some other uses, phosphate may become less dominant in sulfur consumption but remain the leading end use. Ore leaching will be the largest area of sulfur consumption growth (Sulphur, 2005i). World sulfur demand for fertilizer is forecast to increase by 2.1% per year for the next 10 years; industrial demand is predicted to grow by 2.2% per year as a result of increased demand for copper and nickel leaching.

The most important changes in sulfur consumption will be in location. Phosphate fertilizer production, where the most sulfur is consumed, is projected to increase by 1.9% per year through 2014. With new and expanding phosphate fertilizer capacity in Australia, China, Egypt, India, and Saudi Arabia, sulfur demand will grow in these areas at the expense of some phosphate operations elsewhere, transferring sulfur demand rather than creating new demand. The effects were already being felt by the U.S. phosphate industry as reflected in the permanent closure of some facilities and reduced production at others. U.S. phosphate products supply domestic requirements, but a large portion of U.S. production is exported. Brazil, China, and India are primary markets for United States phosphatic fertilizers. As the phosphate fertilizer industries develop in these countries, some of the markets for U.S. material could be lost. Sulfur will be required for phosphate production at new operations, and more sulfur producers will be competing for those markets.

Use of sulfur directly or in compounds as fertilizer is expected to increase, but this use will be dependent on agricultural economies and increased acceptance of the need for sulfur in plant nutrition. If widespread use of plant nutrient sulfur is adopted, then sulfur consumption in that application could grow significantly; thus far, however, growth has been slow.

Industrial sulfur consumption has some prospects for growth, but not enough to consume all projected surplus production. Conversion to or increases in copper leaching by producers that require significantly more sulfuric acid for the leaching operations than was used in 2005 bode well for the sulfur industry. Nickel pressure acid leach operations were demanding increased quantities of sulfur, and more projects have been announced globally. Changes in the preferred methods for producing oxygenated gasoline, especially in Canada and the United States, might result in additional alkylation capacity that would require additional sulfuric acid. Other industrial uses show less potential for expansion. Production is expected to surpass demand well into the future.

Unless less traditional uses for elemental sulfur increase significantly, the oversupply situation will result in tremendous stockpiles accumulating around the world. In the 1970s and 1980s, research was conducted that showed the effectiveness of sulfur in several construction uses that held the promise of consuming huge quantities of sulfur in sulfur-extended asphalt and sulfur concretes. In many instances, these materials were found to be superior to the more conventional products, but their use so far has been very limited. When sulfur prices are high, as they were in 2005, sulfur is less attractive for unconventional applications where low-cost raw materials are the important factor.

Regardless of the prevailing price increases in 2005 that signaled tight supplies, the worldwide oversupply situation is likely to continue. Unless measures are taken to use more sulfur, either voluntarily or through government mandate, large quantities of excess sulfur could be amassed in many areas of the world, including the United States.

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## TABLE 1
## SALIENT SULFUR STATISTICS[1]

(Thousand metric tons of sulfur content and thousand dollars unless otherwise specified)

| | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| United States: | | | | | |
| Quantity: | | | | | |
| Production: | | | | | |
| Frasch | -- | -- | -- | -- | -- |
| Recovered[2] | 8,490 | 8,500 | 8,920 | 9,380 | 8,750 |
| Other | 982 | 772 | 683 | 739 | 711 |
| Total[e] | 9,470 | 9,270 | 9,600 | 10,100 | 9,460 |
| Shipments: | | | | | |
| Frasch | -- | -- | -- | -- | -- |
| Recovered[2] | 8,470 | 8,490 | 8,910 | 9,410 | 8,720 |
| Other | 982 | 772 | 683 | 739 | 711 |
| Total | 9,450 | 9,260 | 9,600 | 10,100 | 9,430 |
| Exports: | | | | | |
| Elemental[3] | 711 | 709 | 840 | 949 | 684 |
| Sulfuric acid | 69 | 48 | 67 | 67 | 110 |
| Imports: | | | | | |
| Elemental | 1,730 | 2,560 | 2,870 [e] | 2,850 [e] | 2,820 [e] |
| Sulfuric acid | 462 | 346 | 297 | 784 | 877 |
| Consumption, all forms[4] | 10,900 | 11,400 | 11,900 | 12,800 | 12,300 |
| Stocks, December 31, producer, Frasch and recovered | 232 | 181 | 206 | 185 | 160 |
| Value: | | | | | |
| Shipments, free on board (f.o.b.) mine or plant: | | | | | |
| Frasch | -- | -- | -- | -- | -- |
| Recovered[e, 2] | 84,700 | 100,000 | 256,000 | 306,000 | 270,000 |
| Other | 49,500 | 35,500 | 34,000 | 61,100 | 80,200 |
| Total | 134,000 | 136,000 | 290,000 | 367,000 | 351,000 |
| Exports, elemental[5] | 52,000 | 43,100 | 54,400 | 63,300 | 55,200 |
| Imports, elemental | 22,100 | 26,800 | 70,600 | 76,800 | 70,500 |
| Price, elemental, f.o.b. mine or plant[e] dollars per metric ton | 9.99 [r] | 11.82 [r] | 28.70 [r] | 32.62 [r] | 30.92 |
| World, production, all forms (including pyrites) | 61,400 [r] | 62,600 [r] | 64,200 [r] | 66,000 [r] | 66,000 [e] |

[e]Estimated. [r]Revised. -- Zero.

[1] Data are rounded to no more than three significant digits except prices; may not add to totals shown.

[2] Includes U.S. Virgin Islands.

[3] Includes exports from the U.S. Virgin Islands to foreign countries.

[4] Consumption is calculated as shipments minus exports plus imports.

[5] Includes value of exports from the U.S. Virgin Islands to foreign countries.

## TABLE 2
## RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE[1]

(Thousand metric tons and thousand dollars)

| | 2004 | | | 2005 | | |
|---|---|---|---|---|---|---|
| | | Shipments | | | Shipments | |
| State | Production | Quantity | Value[e] | Production | Quantity | Value[e] |
| Alabama | 228 | 228 | 7,560 | 236 | 236 | 9,420 |
| California | 1,050 | 1,050 | 20,500 | 1,080 | 1,040 | 26,500 |
| Illinois | 528 | 528 | 10,400 | 567 | 568 | 13,700 |
| Louisiana | 1,280 | 1,280 | 72,600 | 1,150 | 1,150 | 36,600 |
| Michigan and Minnesota | 35 | 38 | 1,040 | 35 | 35 | 974 |
| Mississippi | 495 | 501 | 19,800 | 409 | 404 | 17,900 |
| New Mexico | 34 | 34 | (2) | 32 | 32 | (2) |
| Ohio | 122 | 122 | 3,610 | 111 | 111 | 3,480 |
| Texas | 3,100 | 3,090 | 110,000 | 2,830 | 2,840 | 110,000 |
| Washington | 113 | 113 | (2) | 137 | 137 | (2) |
| Wyoming | 1,540 | 1,540 | 24,200 | 1,300 | 1,310 | 23,900 |
| Other[3] | 849 | 886 | 36,300 | 856 | 865 | 27,500 |
| Total | 9,380 | 9,410 | 306,000 | 8,750 | 8,720 | 270,000 |

[e] Estimated.

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

[2] Some sulfur producers in this State incur expenses to make their products available to consumers.

[3] Includes Arkansas, Colorado, Delaware, Florida, Indiana, Kansas, Kentucky, Montana, New Jersey, North Dakota, Pennsylvania, Utah, Virginia, Wisconsin, and the U.S. Virgin Islands.

## TABLE 3
## RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT[1]

(Thousand metric tons)

| | 2004 | | 2005 | |
|---|---|---|---|---|
| District and source | Production | Shipments | Production | Shipments |
| PAD 1: | | | | |
| Petroleum and coke | 236 | 238 | 234 | 235 |
| Natural gas | 21 | 21 | 19 | 18 |
| Total | 256 | 259 | 253 | 253 |
| PAD 2: | | | | |
| Petroleum and coke | 976 | 978 | 1,040 | 1,040 |
| Natural gas | 43 | 43 | 36 | 36 |
| Total | 1,020 | 1,020 | 1,070 | 1,070 |
| PAD 3:[2] | | | | |
| Petroleum and coke | 4,780 | 4,810 | 4,320 | 4,330 |
| Natural gas | 512 | 510 | 491 | 490 |
| Total | 5,300 | 5,320 | 4,810 | 4,820 |
| PAD 4 and 5: | | | | |
| Petroleum and coke | 1,390 | 1,400 | 1,350 | 1,310 |
| Natural gas | 1,410 | 1,420 | 1,260 | 1,270 |
| Total | 2,800 | 2,810 | 2,610 | 2,580 |
| Grand total | 9,380 | 9,410 | 8,750 | 8,720 |
| Of which: | | | | |
| Petroleum and coke | 7,390 | 7,420 | 6,940 | 6,910 |
| Natural gas | 1,990 | 1,990 | 1,810 | 1,810 |

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

[2] Includes the U.S. Virgin Islands.

## TABLE 4
## BYPRODUCT SULFURIC ACID PRODUCED IN THE UNITED STATES[1, 2]

(Thousand metric tons of sulfur content and thousand dollars)

| Type of plant | 2004 | 2005 |
|---|---|---|
| Copper[3] | 600 | 575 |
| Zinc, lead, and molybdenum[4] | 138 | 137 |
| Total: | | |
| Quantity | 739 | 711 |
| Value | 61,100 | 80,200 |

[1] May include acid produced from imported raw materials.

[2] Data are rounded to no more than three significant digits, may not add to totals shown.

[3] Excludes acid made from pyrites concentrates.

[4] Excludes acid made from native sulfur.

## TABLE 5
## CONSUMPTION OF SULFUR IN THE UNITED STATES[1, 2, 3]

(Thousand metric tons)

| | 2004 | 2005 |
|---|---|---|
| Elemental sulfur: | | |
| Shipments[4] | 9,410 | 8,720 |
| Exports | 949 | 684 |
| Imports[e] | 2,850 | 2,820 |
| Total | 11,300 | 10,900 |
| Byproduct sulfuric acid: | | |
| Shipments[4] | 739 | 711 |
| Exports[5] | 67 | 110 |
| Imports[5] | 784 | 877 |
| Total | 1,460 | 1,480 |
| Grand total | 12,800 | 12,300 |

[e] Estimated.

[1] Crude sulfur or sulfur content.

[2] Data are rounded to no more than three significant digits; may not add to totals shown.

[3] Consumption is calculated as shipments minus exports plus imports.

[4] Includes the U.S. Virgin Islands.

[5] May include sulfuric acid other than byproduct.

## TABLE 6

## SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE[1]

(Thousand metric tons of sulfur content)

| | | Elemental sulfur[2] | | Sulfuric acid (sulfur equivalent) | | Total | |
|---|---|---|---|---|---|---|---|
| SIC[3] | End use | 2004 | 2005 | 2004 | 2005 | 2004 | 2005 |
| 102 | Copper ores | -- | -- | 452 | 395 | 452 | 395 |
| 1094 | Uranium and vanadium ores | -- | -- | 2 | 7 | 2 | 7 |
| 10 | Other ores | -- | -- | 6 | 53 | 6 | 53 |
| 26, 261 | Pulpmills and paper products | W | W | 272 | 267 | 272 | 267 |
| 28, 285, 286, 2816 | Inorganic pigments, paints, and allied products; industrial organic chemicals, other chemical products[4] | W | W | 154 | 312 | 154 | 312 |
| 281 | Other inorganic chemicals | W | W | 108 | 109 | 108 | 109 |
| 282, 2822 | Synthetic rubber and other plastic materials and synthetics | -- | W | 70 | 64 | 70 | 64 |
| 2823 | Cellulosic fibers including rayon | -- | -- | 2 | -- | 2 | -- |
| 283 | Drugs | -- | -- | 1 | 1 | 1 | 1 |
| 284 | Soaps and detergents | -- | -- | 2 | 7 | 2 | 7 |
| 286 | Industrial organic chemicals | -- | -- | 25 | 17 | 25 | 17 |
| 2873 | Nitrogenous fertilizers | -- | -- | 209 | 214 | 209 | 214 |
| 2874 | Phosphatic fertilizers | -- | -- | 6,870 | 7,000 | 6,870 | 7,000 |
| 2879 | Pesticides | -- | -- | 16 | 15 | 16 | 15 |
| 287 | Other agricultural chemicals | 1,970 | 1,770 | 49 | 48 | 2,010 | 1,810 |
| 2892 | Explosives | -- | -- | 10 | 10 | 10 | 10 |
| 2899 | Water-treating compounds | -- | -- | 89 | 67 | 89 | 67 |
| 28 | Other chemical products | -- | -- | 105 | 290 | 105 | 290 |
| 29, 291 | Petroleum refining and other petroleum and coal products | 4,100 | 3,590 | 248 | 188 | 4,350 | 3,780 |
| 30 | Rubber and miscellaneous plastic products | W | W | 4 | 3 | 4 | 3 |
| 331 | Steel pickling | -- | -- | 9 | 52 | 9 | 52 |
| 333 | Nonferrous metals | -- | -- | 3 | 4 | 3 | 4 |
| 33 | Other primary metals | -- | -- | 6 | 10 | 6 | 10 |
| 3691 | Storage batteries (acid) | -- | -- | 29 | 16 | 29 | 16 |
| | Exported sulfuric acid | -- | -- | 26 | 26 | 26 | 26 |
| | Total identified | 6,070 | 5,360 | 8,770 | 9,180 | 14,800 | 14,500 |
| | Unidentified | 801 | 608 | 518 | 503 | 1,320 | 1,110 |
| | Grand total | 6,870 | 5,970 | 9,290 | 9,680 | 16,200 | 15,600 |

W Withheld to avoid disclosing company proprietary data; included with "Unidentified." -- Zero.

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

[2] Does not include elemental sulfur used for production of sulfuric acid.

[3] Standard industrial classification.

[4] No elemental sulfur was used in inorganic pigments, paints, and allied products.

## TABLE 7
## U.S. EXPORTS OF ELEMENTAL SULFUR, BY COUNTRY[1, 2]

(Thousand metric tons and thousand dollars)

| | 2004 | | 2005 | |
|---|---|---|---|---|
| Country | Quantity | Value | Quantity | Value |
| Argentina | 12 | 604 | 59 | 3,000 |
| Brazil | 520 | 31,800 | 165 | 11,800 |
| Canada | 88 | 6,070 | 110 | 8,610 |
| Chile | 24 | 1,700 | 3 | 928 |
| China | 167 | 9,880 | 248 | 20,200 |
| Colombia | 19 | 1,380 | 6 | 561 |
| Mexico | 24 | 1,960 | 31 | 1,950 |
| Morocco | 35 | 1,740 | 15 | 491 |
| Senegal | 18 | 896 | 18 | 1,690 |
| Switzerland | 19 | 1,090 | 12 | 608 |
| Venezuela | 1 | 1,370 | 3 | 1,190 |
| Other | 22 r | 4,810 r | 14 | 4,250 |
| Total | 949 | 63,300 | 684 | 55,200 |

r Revised.

[1] Includes exports from the U.S. Virgin Islands.

[2] Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

## TABLE 8
## U.S. EXPORTS OF SULFURIC ACID (100% $H_2SO_4$), BY COUNTRY[1]

| | 2004 | | 2005 | |
|---|---|---|---|---|
| Country | Quantity (metric tons) | Value (thousands) | Quantity (metric tons) | Value (thousands) |
| Aruba | 2,630 | $217 | 1,740 | $399 |
| Brazil | 17 | 15 | 49,400 | 2,040 |
| Canada | 98,700 | 7,730 | 101,000 | 8,120 |
| Chile | 8,270 | 942 | -- | -- |
| China | 2,050 | 562 | 2,320 | 449 |
| Dominican Republic | 2,410 | 279 | 6,970 | 562 |
| Germany | 394 | 45 | 6,530 | 1,240 |
| Ireland | 3,490 | 1,530 | 2,360 | 1,190 |
| Israel | 236 | 349 | 257 | 355 |
| Italy | 4 | 17 | 2,810 | 322 |
| Japan | 67 | 118 | 3,920 | 623 |
| Korea, Republic of | 157 | 18 | 3,200 | 436 |
| Malaysia | 64 | 44 | 6,700 | 954 |
| Mexico | 44,100 | 2,190 | 3,000 | 683 |
| Netherlands Antilles | 10,200 | 484 | 12,000 | 633 |
| Saudi Arabia | 2,230 | 4,020 | 375 | 1,010 |
| Singapore | 52 | 55 | 11,600 | 1,600 |
| Taiwan | 595 | 454 | 15,700 | 2,190 |
| Trinidad and Tobago | 6,520 | 395 | 18,000 | 908 |
| United Kingdom | 142 | 24 | 371 | 333 |
| Venezuela | 16,800 | 849 | 86,500 | 4,570 |
| Other | 5,110 r | 982 r | 3,130 | 854 |
| Total | 204,000 | 21,300 | 338,000 | 29,500 |

r Revised. -- Zero.

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

## TABLE 9
## U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY[1]

(Thousand metric tons and thousand dollars)

|  | 2004 |  | 2005 |  |
|---|---|---|---|---|
| Country | Quantity | Value[2] | Quantity | Value[2] |
| Canada | 2,010 e | 31,300 | 1,970 e | 33,500 |
| Mexico | 545 | 28,200 | 427 | 18,600 |
| Venezuela | 80 e | 16,100 | 409 e | 16,800 |
| Other | 215 r, e | 1,200 r | 14 e | 1,600 |
| Total | 2,850 e | 76,800 | 2,820 e | 70,500 |

[e] Estimated. [r] Revised.

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

[2] Declared customs valuation.

Source: U.S. Census Bureau and PentaSul North American Sulphur Service as adjusted by the U.S. Geological Survey.

## TABLE 10
## U.S. IMPORTS OF SULFURIC ACID (100% $H_2SO_4$), BY COUNTRY[1]

|  | 2004 |  | 2005 |  |
|---|---|---|---|---|
| Country | Quantity (metric tons) | Value[2] (thousands) | Quantity (metric tons) | Value[2] (thousands) |
| Canada | 1,920,000 | $79,400 | 2,010,000 | $89,400 |
| Chile | -- | -- | 100,000 | 5,380 |
| Mexico | 217,000 | 5,670 | 398,000 | 9,440 |
| Other | 263,000 r | 19,200 r | 178,000 | 18,100 |
| Total | 2,400,000 | 104,000 | 2,680,000 | 122,000 |

[r] Revised. -- Zero.

[1] Data are rounded to no more than three significant digits; may not add to totals shown.

[2] Declared cost, insurance, and freight paid by shipper valuation.

Source: U.S. Census Bureau.

## TABLE 11
## SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

| Country and source[3] | 2001 | 2002 | 2003 | 2004 | 2005[e] |
|---|---|---|---|---|---|
| Australia, byproduct:[e] | | | | | |
| Metallurgy | 817 | 899 | 863 | 865 | 950 |
| Petroleum | 45 | 60 | 60 | 60 | 60 |
| Total | 862 | 959 | 923 | 925 | 1,010 |
| Canada, byproduct: | | | | | |
| Metallurgy | 1,124 [r] | 1,109 [r] | 992 [r] | 1,089 [r] | 1,057 [p] |
| Natural gas, petroleum, tar sands | 8,320 [r] | 7,816 [r] | 8,036 [r] | 8,421 [r] | 7,916 [p] |
| Total | 9,444 [r] | 8,925 [r] | 9,028 [r] | 9,510 [r] | 8,973 [p] |
| Chile, byproduct, metallurgy[e] | 1,160 | 1,275 [4] | 1,430 | 1,510 | 1,660 |
| China:[e] | | | | | |
| Elemental | 420 [r] | 540 [r] | 700 [r] | 820 [r] | 900 |
| Pyrites | 3,090 | 3,240 | 3,400 | 3,730 | 4,010 |
| Byproduct, metallurgy | 2,000 | 2,200 | 2,400 | 2,600 | 2,800 |
| Total | 5,510 [r] | 5,980 [r] | 6,500 [r] | 7,150 [r] | 7,710 |
| Finland:[e] | | | | | |
| Pyrites | 270 | 359 | 341 | 336 | 350 |
| Byproduct: | | | | | |
| Metallurgy | 227 | 308 | 305 | 301 | 300 |
| Petroleum | 46 | 55 | 60 | 65 | 70 |
| Total | 543 | 722 | 706 | 702 | 720 |
| France, byproduct:[e] | | | | | |
| Natural gas and petroleum | 837 | 787 | 816 | 765 | 750 |
| Unspecified | 260 | 229 | 196 | 196 | 195 |
| Total | 1,100 | 1,020 | 1,010 | 961 | 945 |
| Germany: | | | | | |
| Pyrites | -- [r] | -- | -- | -- | -- |
| Unspecified, marketable | 988 | 1,093 | 1,014 | 939 | 940 |
| Byproduct: | | | | | |
| Metallurgy | 684 | 754 | 701 | 591 | 600 |
| Natural gas and petroleum | 1,749 | 1,745 | 1,661 | 977 [r] | 977 |
| Total | 3,421 [r] | 3,592 [r] | 3,376 [r] | 2,506 [r] | 2,520 |
| India:[e] | | | | | |
| Pyrites | 32 | 32 | 32 | 32 | 32 |
| Byproduct: | | | | | |
| Metallurgy | 458 | 458 | 539 | 539 | 580 |
| Natural gas and petroleum | 526 | 371 | 451 | 501 | 520 |
| Total | 1,020 | 861 | 1,020 | 1,070 | 1,130 |
| Iran, byproduct:[e] | | | | | |
| Metallurgy | 50 | 50 | 50 | 60 | 60 |
| Natural gas and petroleum | 880 [4] | 1,200 [4] | 1,310 | 1,400 | 1,400 |
| Total | 930 | 1,250 | 1,360 | 1,460 | 1,460 |
| Italy, byproduct:[e] | | | | | |
| Metallurgy | 203 | 142 | 127 | 113 | 115 |
| Petroleum | 540 | 560 | 565 | 575 | 570 |
| Total | 743 | 702 | 692 | 688 | 685 |
| Japan, byproduct: | | | | | |
| Metallurgy | 1,319 | 1,326 | 1,281 | 1,263 | 1,330 |
| Petroleum | 2,424 | 1,865 | 1,951 | 1,895 [r] | 1,930 |
| Total | 3,743 | 3,191 | 3,232 | 3,158 [r] | 3,260 |

See footnotes at end of table.

### TABLE 11—Continued
### SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

| Country and source[3] | 2001 | 2002 | 2003 | 2004 | 2005[e] |
|---|---|---|---|---|---|
| Kazakhstan, byproduct:[e] | | | | | |
| Metallurgy | 310 | 260 | 325 | 325 | 325 |
| Natural gas and petroleum | 1,400 | 1,600 | 1,600 | 1,650 | 1,700 |
| Total | 1,710 | 1,860 | 1,930 | 1,980 | 2,030 |
| Korea, Republic of, byproduct:[e] | | | | | |
| Metallurgy | 665 | 737 | 797 [r] | 796 | 800 |
| Petroleum | 690 | 687 | 757 | 879 | 885 |
| Total | 1,360 | 1,420 | 1,550 [r] | 1,680 | 1,690 |
| Kuwait, byproduct, natural gas and petroleum[e] | 524 | 634 | 714 | 682 | 700 |
| Mexico, byproduct: | | | | | |
| Metallurgy[e] | 572 | 588 | 539 | 703 | 700 |
| Natural gas and petroleum | 878 | 877 | 1,052 | 1,122 | 1,017 [4] |
| Total | 1,450 | 1,465 | 1,591 | 1,825 | 1,717 [4] |
| Netherlands, byproduct:[e] | | | | | |
| Metallurgy | 126 | 124 | 131 | 137 | 135 |
| Petroleum | 384 | 373 | 408 | 410 | 400 |
| Total | 510 | 497 | 539 | 547 | 535 |
| Poland:[5] | | | | | |
| Frasch | 942 | 760 | 762 [e] | 750 [e] | 750 |
| Byproduct: | | | | | |
| Metallurgy[e] | 277 [4] | 276 [r] | 294 [r] | 290 [r] | 280 |
| Petroleum | 133 | 180 | 180 [r, e] | 190 [r, e] | 190 |
| Total[e] | 1,352 [4] | 1,220 [r] | 1,240 [r] | 1,230 [r] | 1,220 |
| Russia:[e, 6] | | | | | |
| Native | 50 | 50 | 50 | 50 | 50 |
| Pyrites | 320 | 350 | 350 | 300 | 300 |
| Byproduct: | | | | | |
| Metallurgy | 460 | 500 | 520 | 570 | 600 |
| Natural gas | 5,300 | 5,600 | 5,800 | 6,000 | 6,000 |
| Total | 6,130 | 6,500 | 6,720 | 6,920 | 6,950 |
| Saudi Arabia, byproduct, all sources[e] | 2,350 | 2,360 | 2,180 | 2,230 | 2,300 |
| South Africa: | | | | | |
| Pyrites, S content, from gold mines | 150 | 183 | 176 | 165 | 133 [p] |
| Byproduct: | | | | | |
| Metallurgy, copper, platinum, zinc plants | 265 [e] | 179 | 174 | 180 | 250 |
| Petroleum | 123 | 170 | 264 | 288 | 410 |
| Total | 538 | 532 | 614 | 633 | 793 |
| Spain:[e] | | | | | |
| Pyrites | 71 | -- | -- | -- | -- |
| Byproduct: | | | | | |
| Coal, lignite, gasification | 1 | 1 | 1 | 1 | 1 |
| Metallurgy | 461 | 544 | 560 | 488 | 475 |
| Petroleum | 135 | 140 | 145 | 145 | 140 |
| Total | 668 | 685 | 706 | 634 | 616 |
| United Arab Emirates, byproduct, natural gas and petroleum[e] | 1,490 | 1,900 | 1,900 | 1,930 | 1,950 |
| United States, byproduct: | | | | | |
| Metallurgy | 982 | 772 | 683 | 739 | 711 [4] |
| Natural gas | 2,000 | 1,760 | 1,940 | 1,990 | 1,810 [4] |

See footnotes at end of table.

## TABLE 11—Continued
## SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

| Country and source[3] | 2001 | 2002 | 2003 | 2004 | 2005[e] |
|---|---|---|---|---|---|
| United States, byproduct—Continued: | | | | | |
| Petroleum | 6,480 | 6,750 | 6,970 | 7,390 | 6,940 [4] |
| Total | 9,470 | 9,270 | 9,600 | 10,100 | 9,460 [4] |
| Uzbekistan, byproduct:[e] | | | | | |
| Metallurgy | 160 | 170 | 170 | 170 | 170 |
| Natural gas and petroleum | 300 | 350 | 350 | 350 | 350 |
| Total | 460 | 520 | 520 | 520 | 520 |
| Venezuela, byproduct, natural gas and petroleum | 340 | 570 | 560 [e] | 800 [e] | 800 |
| Other[e] | 4,630 [r] | 4,700 [r] | 4,570 [r] | 4,640 [r] | 4,660 |
| Of which: | | | | | |
| Frasch | 24 | 23 | 19 | 20 | 20 |
| Native[7] | 523 [r] | 502 [r] | 283 [r] | 251 [r] | 217 |
| Pyrites | 214 [r] | 189 [r] | 200 [r] | 192 [r] | 187 |
| Unspecified | 1,120 | 1,090 | 1,140 | 1,150 [r] | 1,190 |
| Of which: | | | | | |
| Byproduct: | | | | | |
| Metallurgy | 1,260 [r] | 1,320 [r] | 1,380 [r] | 1,350 [r] | 1,350 |
| Natural gas | 226 | 255 | 305 | 365 | 365 |
| Natural gas and petroleum, undifferentiated | 420 [r] | 441 [r] | 405 [r] | 425 [r] | 427 |
| Petroleum | 845 [r] | 882 [r] | 843 [r] | 881 [r] | 900 |
| Grand total | 61,400 [r] | 62,600 [r] | 64,200 [r] | 66,000 [r] | 66,000 |
| Of which: | | | | | |
| Frasch | 966 | 783 | 781 | 770 | 770 |
| Native[7] | 993 [r] | 1,090 [r] | 1,030 [r] | 1,120 [r] | 1,170 |
| Pyrites | 4,150 [r] | 4,350 [r] | 4,500 [r] | 4,760 [r] | 5,010 |
| Unspecified | 4,720 [r] | 4,780 [r] | 4,530 [r] | 4,510 [r] | 4,630 |
| Byproduct: | | | | | |
| Coal, lignite, gasification[e] | 1 | 1 | 1 | 1 | 1 |
| Metallurgy | 13,600 [r] | 14,000 [r] | 14,300 [r] | 14,700 [r] | 15,300 |
| Natural gas | 7,530 [r] | 7,610 [r] | 8,050 [r] | 8,360 [r] | 8,170 |
| Natural gas, petroleum, tar sands, undifferentiated | 17,700 [r] | 18,300 [r] | 18,900 [r] | 19,000 [r] | 18,500 |
| Petroleum | 11,800 [r] | 11,700 [r] | 12,200 [r] | 12,800 [r] | 12,500 |

[e] Estimated. [p] Preliminary. [r] Revised. -- Zero.

[1] World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2] Table includes data available through July 17, 2006.

[3] The term "source" reflects the means of collecting sulfur and the type of raw material. Sources listed include the following: Frasch recovery; native comprising all production of elemental sulfur by traditional mining methods (thereby excluding Frasch); pyrites (whether or not the sulfur is recovered in the elemental form or as acid); byproduct recovery, either as elemental sulfur or as sulfur compounds from coal gasification, metallurgical operations including associated coal processing, crude oil and natural gas extraction, petroleum refining, tar sand cleaning, and processing of spent oxide from stack-gas scrubbers; and recovery from processing mined gypsum. Recovery of sulfur in the form of sulfuric acid from artificial gypsum produced as a byproduct of phosphatic fertilizer production is excluded, because to include it would result in double counting. Production of Frasch sulfur, other native sulfur, pyrite-derived sulfur, mined gypsum derived sulfur, byproduct sulfur from extraction of crude oil and natural gas, and recovery from tar sands are all credited to the country of orgin of the extracted raw materials. In contrast, byproduct recovery from metallurgical operations, petroleum refineries, and spent oxides are credited to the nation where the recovery takes place, which is not the original source country of the crude product from which the sulfur is extracted.

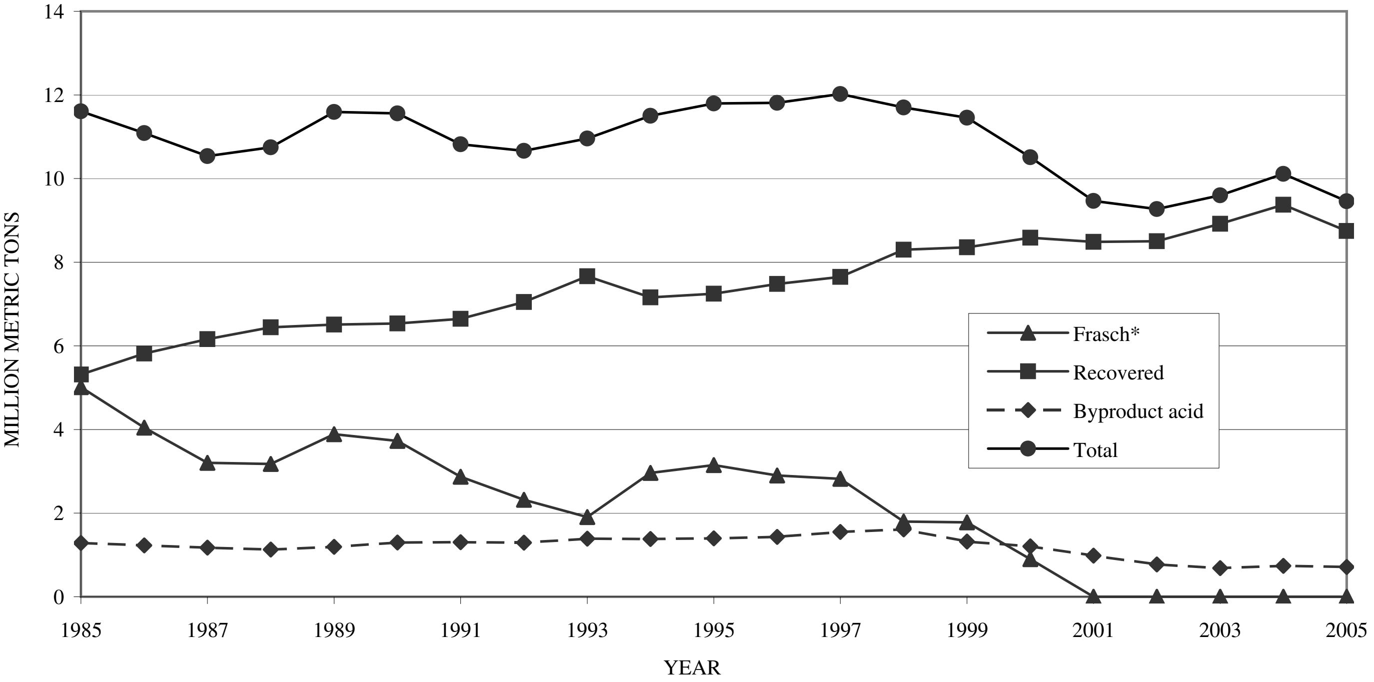
[4] Reported figure.

[5] Government of Poland sources report total Frasch and native mined elemental sulfur output annually, undifferentiated; this figure has been divided between Frasch and other native sulfur on the basis of information obtained from supplementary sources.

[6] Sulfur is believed to be produced from Frasch and as a petroleum byproduct; however, information is inadequate to formulate estimates.

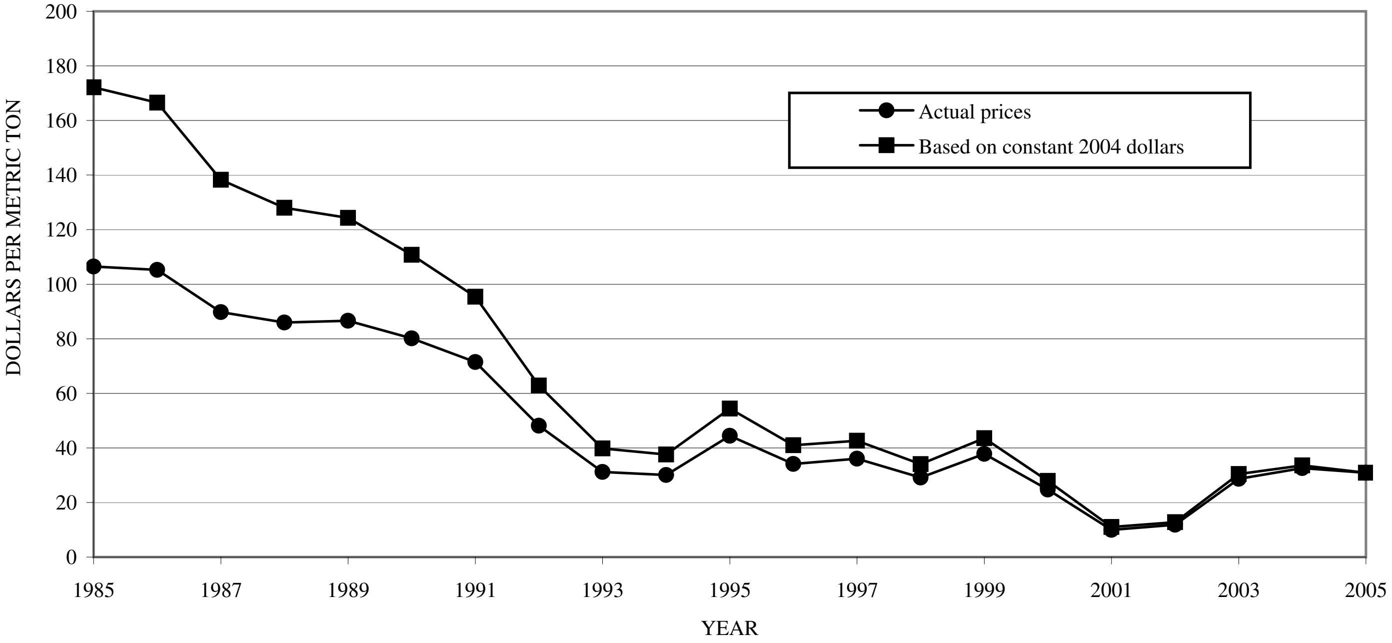
[7] Includes "China, elemental."

FIGURE 1
TRENDS IN SULFUR PRODUCTION IN THE UNITED STATES



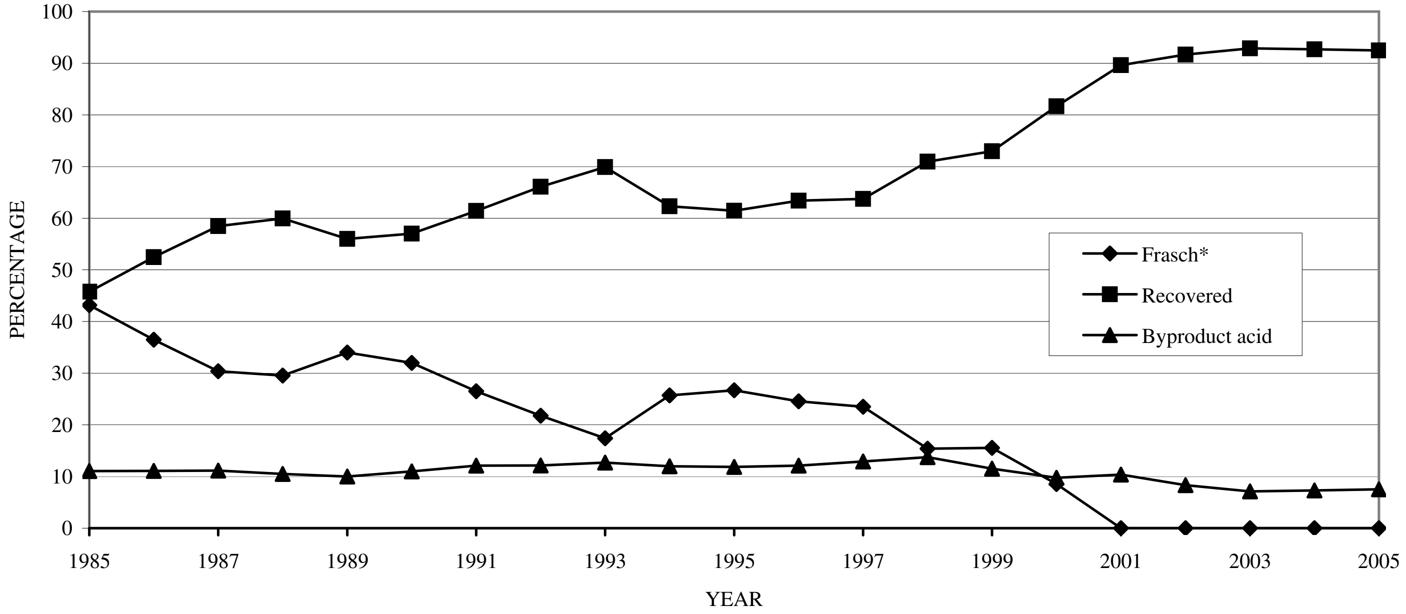
*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to avoid disclosing company proprietary data. Data for 1994 through 2000 are estimates.

FIGURE 2
ESTIMATED AVERAGE PRICE OF SULFUR IN ACTUAL AND CONSTANT DOLLARS[1]



[1] Based on the reported average value for elemental sulfur (Frasch and recovered), free on board mine and/or plant.

FIGURE 3
PERCENTAGE OF SULFUR PRODUCTION BY SOURCE



*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to avoid disclosing company proprietary data. Data for 1994 through 2000 are estimates.

FIGURE 4
TRENDS IN SALIENT SULFUR STATISTICS