SULFUR

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After nearly a century of world dominance in the production of sulfur in all forms, the United States was edged out by Canada as the world's largest sulfur producer in 2001. Both countries, however, had virtually the same production with only about 1% separating the two. Worldwide, production of native sulfur and pyrites continued to decline as environmental regulations forced increased sulfur recovery to limit atmospheric emissions of sulfur dioxide. Growth in sulfur recovery continued to outpace sulfur demand, which resulted in increased stocks worldwide.

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 industrial and fertilizer complexes. 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 chemical; 40.1 million metric tons (Mt), which is equivalent to about 13.1 Mt of elemental sulfur, was produced in 2001; this was slightly more than that of 2000 (U.S. Census Bureau, 2002a).

In 2001, domestic production of sulfur in all forms was 10% lower than that of 2000; shipments, consumption, imports, and prices decreased (table 1; fig. 1, 2). The United States maintained its position as the leading world consumer of sulfur and sulfuric acid. The quantity of sulfur recovered during the refining of petroleum continued the upward trend established in 1939 by increasing slightly. Sulfur recovered during natural gas processing decreased by 11%. For the first time since the beginning of the 20th century, no sulfur was produced in the United States by using the Frasch process because the last domestic mine closed in 2000. Shipments were slightly lower than production, thus causing stocks to increase by 12%.

Byproduct sulfuric acid from the Nation's nonferrous smelters and roasters produced as a result of laws restricting sulfur dioxide emissions supplied a significant quantity of sulfuric acid to the domestic merchant (commercial) acid market. Production from this sector decreased by 4% because the three copper smelters that closed in 1999 did not reopen and production was down at lead and molybdenum operations.

Estimated world sulfur production was slightly lower in 2001 than in 2000 (table 1). Frasch production was lower because sulfur mines in Poland and the United States closed. Recovered elemental sulfur is produced primarily during the processing of natural gas and crude petroleum. At least 95% of the world's elemental sulfur production came from recovered sources; this was slightly higher than that of 2000. Some sources of byproduct sulfur are unspecified, which means that the material could be elemental or byproduct sulfuric acid. The quantity of sulfur supplied from recovered sources was dependent on the world demand for fuels, nonferrous metals, and petroleum products, not for sulfur.

World sulfur consumption remained about the same; about 50% was used in fertilizer production, and the remainder, in a myriad of other industrial uses. World trade of elemental sulfur increased by 8% from the levels recorded in 2001. Worldwide inventories of elemental sulfur were higher.

Legislation and Government Programs

Early in 2000, the U.S. Environmental Protection Agency (EPA) issued the final rule for reduced sulfur content of gasoline, as part of tier 2 of the 1990 Clean Air Act Amendments. The standards were nationwide standards with the implementation time extended for some States and for some refining facilities. By 2006, the sulfur content in gasoline must average 30 parts per million (ppm) with an upper limit of 80 ppm. States in the Rocky Mountain region and Alaska were given until 2007 to reach standards because those States generally had better air quality than other States. Small refineries with fewer than 1,500 employees or less than 155,000 barrels per day (bbl/d) of processing capacity were not required to meet interim goals until 2008 when the national limits are to be imposed. The 2008 deadline could be delayed until 2010 if the refiners could demonstrate a severe economic hardship. Small refineries received special consideration because the installation of new equipment in small facilities could be economically damaging (Oil & Gas Journal, 2000b).

Three small U.S. refineries have petitioned the EPA to delay implementing sulfur gasoline limits. These small operations in Kansas, Pennsylvania, and Wyoming say they cannot afford to meet the stricter limitations. A refinery in Illinois closed in January rather than incur the costs of upgrading to meet new specifications, and the owner was trying to divest itself of three other refineries. Another Kansas company was seeking a buyer for its refinery rather than incur the costs of an upgrade (Sulphur, 2001w).

In December 2000, new sulfur standards for diesel fuel reduced the allowable content to 15 ppm from 500 ppm; this was a 97% decrease. The EPA reduced diesel sulfur levels in a first step to clean up emissions from heavy-duty trucks and buses. In addition to reducing sulfur dioxide emissions from diesel engines, changes were made because the new emission control apparatus needed to reduce particulate emissions from these vehicles could not operate effectively unless sulfur levels in the fuel were significantly reduced. The agency estimated the cost of diesel regulations to be 4 to 5 cents per gallon (Oil & Gas Journal, 2001b).

The petroleum refining industry was concerned, however, that the cost of compliance might be significantly higher than the

EPA estimate—in the range of 15 to 50 cents per gallon. Costs that high could make it economically unfeasible for some facilities to install the necessary apparatus, thus forcing closure of refining capacity and perhaps causing shortages in supply (Chemical Market Reporter, 2001). Low-sulfur diesel presented more technological challenges than low-sulfur gasoline and required more substantial investments for high-pressure hydrotreating facilities; the sulfur compounds found in diesel are more difficult to remove than those found in gasoline (Moyse, 2000). Refineries had several options for reducing sulfur levels to meet new regulations. The least expensive choice was using advanced catalysts in desulfurization units (Garritsen and others, 2000). Other treatment options included selective absorption, ammonia conversion, biodesulfurization, catalytic distillation, and solvent extraction.

Concerns remained about how the regulations addressed the issues of timing and transportation. The required timeframe for implementing the new diesel regulations was approximately the same as that for gasoline. Questions were raised as to whether the refining industry would be able to make the required upgrades to diesel and gasoline facilities simultaneously without compromising the availability of either product. In addition, most diesel fuel is transported via pipelines that also transport home heating oil for which no new sulfur requirements were enacted. Industry officials believed that preventing diesel product contamination from the pipelines that also carried the higher sulfur heating oil would be difficult (Hess, 2000).

The EPA was working on new emission standards for large ocean-going vessels that were expected to go into effect by the end of 2002. Ships sailing close to shore in places like the Gulf of Mexico and the English Channel are contributing to onshore pollution. Traditionally, the Maritime Pollution Convention (Marpol) sets standards for shipping emissions and the allowable sulfur content of marine fuels, but the EPA intended to impose standards for ships in U.S. waters if Marpol did not act (Sulphur, 2001h).

Production

Elemental Sulfur.—Production statistics were collected on a monthly basis and published in the U.S. Geological Survey (USGS) monthly sulfur Mineral Industry Surveys. Of the 115 operations to which survey requests were sent, all responded; this represented 100% of the total production shown in table 1. In 2001, production was 11% lower than that of 2000. Shipments decreased by 13%, but the value of shipments decreased by an astounding 65% owing to a tremendous decrease in the average unit value of elemental sulfur and the decreased tonnage. Trends in sulfur production are shown in figure 2.

Frasch.—Native sulfur associated with the caprock of salt domes and in sedimentary deposits was mined by the Frasch hot-water method in which the native sulfur was melted underground with super-heated water and brought to the surface by compressed air. Freeport-McMoRan Sulphur Inc. (a subsidiary of McMoRan Exploration Co.) was the last remaining Frasch producer in the United States. When it closed the last Frasch mine, Main Pass, in 2000, it cited low sulfur prices and increased operating expenses for the early closure, especially the high price of natural gas that was used to heat the water to melt the sulfur (Fertilizer Markets, 2000b).

Main Pass was a mine operated on a salt dome sulfur deposit in the Gulf of Mexico, about 51 kilometers (km) (32 miles) from the coast of Louisiana. The Main Pass offshore complex, which was more than 1.6 km (1 mile) long and was the largest structure in the Gulf, had a production capacity of more than 5,500 metric tons per day (t/d) (McMoRan Exploration Co., 2000, p. 11-12). Production began in 1991 at a development cost of $880 million (Chemical & Engineering News, 2000).

When Freeport announced plans to close its mine, it proposed to concentrate on its sulfur transportation and marketing business and to continue meeting its supply contracts through purchases of recovered sulfur. To this end, Freeport sold its idle sulfur property in Pecos County, TX, which included the mine site, a powerplant, and surrounding real estate, for $3.2 million late in 2000 (Fertilizer Markets, 2001a). In 2001, the company sold its sulfur and salt lease at Main Pass to Trinity Storage Services, L.P., but retained the right to produce sulfur and oil at that location. Both companies will be responsible for abandonment and reclamation costs (Fertilizer Markets, 2001b).

The company offered the sulfur logistics business for sale, for about $80 million (Fertilizer Markets, 2001a). In addition to the mine, Freeport's operations included facilities for forming, loading, remelting, and transporting sulfur in Galveston, TX, Port Sulphur, LA, and Tampa, FL, and commercial contracts associated with the sulfur-handling business. After extended negotiations and considerations, the company sold these assets to Gulf Sulphur Services Ltd., LLP (a joint venture between IMC Global Inc. and Savage Industries Inc.) in 2002. The venture will be operated by Savage Industries (McMoRan Exploration Co., 2002).

Recovered.—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 44 companies at 114 plants in 26 States and 1 plant in the U.S. Virgin Islands. Most of these plants were small with only 30 reporting production that exceeded 100,000 metric tons per year (t/yr). By source, 78% of recovered elemental sulfur production came from petroleum refineries or satellite plants that treated refinery gases and coking plants, and the remainder was produced at natural gas treatment plants. Mergers and acquisitions contributed to the expanding dominance of large companies in the industry. The largest recovered sulfur producers, all with more than 500,000 metric tons (t) of sulfur production, in descending order of production, were Exxon Mobil Corp., ChevronTexaco Corp., BP p.l.c., Valero Energy Corp., Phillips Petroleum Co., and Motiva Enterprises LLC. The 49 plants owned by these companies accounted for 65% of recovered sulfur output during the year. Recovered sulfur production by State and region is listed in tables 2 and 3.

Of the 15 largest refineries in the world, 5 were in the United States. In descending order of refining capacity, they were Hovensa LLC's St. Croix, U.S. Virgin Islands, refinery; ExxonMobil's Baytown, TX, and Baton Rouge, LA, refineries;

and BP's Texas City, TX, and Whiting, IN, refineries, all were significant sulfur producing facilities (Chang, 2000). Refining capacity does not necessarily mean that these refineries were the largest producers of refinery sulfur. Sulfur production depends on installed sulfur recovery capacity as well as the types of crude that are refined at the specific refineries. Large refineries that process low-sulfur crudes may have relatively low sulfur production.

In recent years, consolidation in the petroleum industry has reduced the number of companies operating sulfur recovery operations, although the number of sulfur plants has remained about the same. In 1998, Amoco Co. and British Petroleum Co., p.l.c., merged to form BP Amoco p.l.c. (BP Amoco p.l.c., 1999). In 1999, the U.S. Federal Trade Commission (FTC) approved the merger of Exxon Corp. and Mobil Corp. to form Exxon Mobil Corp. (Chang, 1999). In 2000, the merger of BP Amoco p.l.c. with Atlantic Richfield Co. (ARCO) to form BP Amoco ARCO p.l.c. was approved, and the company name was simplified to BP p.l.c. (Oil & Gas Journal, 2000a).

More mergers were completed and proposed in 2001. The FTC approved the merger of Chevron Corp. and Texaco Inc. to create ChevronTexaco Corp. provided the companies completed the required divestitures of specified Texaco units. A Michigan firm bought Texaco's aviation fuels and services business. Texaco sold its interests in joint ventures with Shell Oil Co. and Saudi Oil Co. to those companies. This merger created the third largest oil and gas company in the United States (Oil & Gas Journal, 2001a). As with other recent mergers, the companies merged to be more competitive with other giant oil companies. They planned to improve their competitiveness for developing new oilfields and sources of energy (Hoffman, 2000).

In another deal, Valero and Ultramar Diamond Shamrock Corp. merged following approval from the FTC. The combined company retained the name Valero Energy Corp. A condition for approval of the merger was that the company was required to sell one refinery in California and a portion of the retail outlets in the area. The new company became the third largest refiner in the United States (Valero Energy Corp., 2001).

Phillips was busy with acquisitions and mergers during 2001. The company received approval to purchase Tosco Corp. in a deal that required no divestitures. With the purchase of Tosco, Phillips operated 10 U.S. refineries and 1 in Ireland (Oil & Gas Journal, 2001a). After the completion of the Tosco purchase, Conoco Inc. and Phillips signed a merger agreement to create ConocoPhillips. When the merger is completed, ConocoPhillips will become the third largest integrated U.S. energy company. The merger was expected to be completed during the second half of 2002 after the companies receive shareholder and FTC approval (Phillips Petroleum Co., 2001).

In recent years, mergers also took place in the natural gas industry. In 2000, Duke Energy Corp. merged with Phillips' gas gathering, processing, and marketing unit to form Duke Energy Field Services, LLC [Duke Energy (70%) and Phillips (30%)] (Duke Energy Corp., 2001, p. 12). El Paso Energy Corp. acquired The Coastal Corp. The El Paso Energy and Coastal merger was completed early in 2001, and the name was changed to El Paso Corp. (El Paso Corp., 2001; El Paso Energy Corp., 2001).

Several refining companies were in the process of upgrading their facilities to produce low sulfur fuels from higher sulfur crude oil, most of which were not completed in 2001. ExxonMobil was building a 40,000-bbl/d coker at its Baytown refinery to handle 530,000 bbl/d of Mexican sour crude from Petróleos Mexicano S.A. de C.V. (Pemex). The upgrades were designed to increase the quality of the fuels produced at Baytown. Sulfur production at the plant was likely to increase to between 350,000 t/yr and 360,000 t/yr from about 300,000 t/yr (North American Sulphur Service, 2000a). Marathon Ashland Petroleum LLC was upgrading and adding sulfur recovery capacity at its Garyville, LA, refinery to handle imports from Pemex (Cunningham, 1999b). The Premcor Refining Group Inc. was upgrading its Port Arthur, TX, refinery to handle more heavy crude. New sulfur recovery capacity was being installed to increase production to more than 200,000 t/yr from 130,000 t/yr (North America Sulphur Service, 2000b). Other companies were involved in joint ventures in which foreign sour crude producers contributed financing for the upgraded facilities. Shell and Pemex's Deer Park, TX, refinery upgrade to enable the refinery to handle heavy sour Maya crude from Mexico was completed by midyear. The plant has the capacity to produce 270 t/d of sulfur from 340,000 bbl/d of crude petroleum (Sulphur, 2001l). In 2000, Phillips and Petroleos de Venezuela S.A. (PdVSA) completed installation of a new vacuum distillation unit and a coker at Phillips' Sweeny, TX, refinery to enable the facility to handle heavy crudes like those produced by PdVSA from the Venezuelan Orinoco Basin (Oil & Gas Journal, 2000c).

Byproduct Sulfuric Acid.**—**Sulfuric acid production at copper, lead, molybdenum, and zinc roasters and smelters accounted for about 11% of the total domestic production of sulfur in all forms, this was a slight increase compared with that of 2000 (table 4). Four acid plants operated in conjunction with copper smelters, and six were accessories to lead, molybdenum, and zinc smelting and roasting operations. Even with the cutbacks at copper smelters, the four largest acid plants were associated with copper mines and accounted for 83% of the output. The largest copper producers—ASARCO Incorporated, Kennecott Utah Copper Corp., and Phelps Dodge Corp.—operated a total of four sulfuric acid plants at primary copper smelters.

Byproduct acid decreased by 4% from that of 2000 because three of the seven copper smelters in the United States remained closed during the year, which kept production from copper low. The 1999 closures resulted from a serious slump in the world copper industry, thus driving adjusted copper prices lower than they had been at any time in the 20th century (McCoy, 1999). Production at lead and molybdenum smelters was 36% lower in 2001, but this decrease had limited impact on total byproduct acid production because copper is so dominant.

Consumption

Apparent domestic consumption of sulfur in all forms was 14% lower than that of 2000 (table 5). Of the sulfur consumed, 80% was obtained from domestic sources, such as elemental sulfur (71%) and byproduct acid (9%), compared with 78% in 2000 and 77% in 1999. The remaining 20% was supplied by imports of recovered elemental sulfur (16%) and sulfuric acid

(4%). 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 largest sulfur end use, sulfuric acid, represented 75% of reported consumption with an identified end use. Some identified sulfur end uses were tabulated 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 an assumption 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. Although apparent consumption decreased in 2001, data based on USGS surveys of sulfur and sulfuric acid producers showed that reported U.S. consumption of sulfur in sulfuric acid (100% basis) decreased slightly, but total sulfur consumption was 6% higher than that of 2000. These discrepancies may be attributed to inaccuracies in reporting that could have resulted in double counting.

Agriculture was the largest sulfur-consuming industry, although consumption in that end use decreased to 8.2 Mt compared with 8.6 Mt in 2000. Reported consumption in phosphatic fertilizers was 4% lower than that of 2000; this was a result of decreased production at phosphoric acid plants. According to export data from the U.S. Census Bureau, the estimated quantity of sulfur needed to manufacture exported phosphatic fertilizers decreased by 7% to 4.5 Mt.

The second largest end use for sulfur was in petroleum refining, and other petroleum and coal products. After a few years of relatively stable consumption in this sector, producers of sulfur and sulfuric acid reported an increase of 30% in the consumption of sulfur in that end use.

Demand for sulfuric acid in copper ore leaching, which was the third largest end use, increased slightly as a result of increased copper production from leaching operations. All copper producers, even companies that closed smelter operations, continued to operate their solvent extraction-electrowinning (SX-EW) operations in which weak sulfuric acid dissolves copper as it percolates through specially prepared beds of copper minerals. The copper is then concentrated through a solvent extraction process, and the concentrated solution undergoes an electrowinning process that produces 99.99% copper cathode (Phelps Dodge Corp., 1999).

Phelps Dodge Mining Co.'s project to convert its Morenci, AZ, operations to 100% SX-EW was completed in March 2001. Operations were expected to reach full capacity by the end of the year. The mine's crushing and conveying system was expanded. A mobile conveying apparatus was installed to stack crushed ore onto leach piles. New solvent extraction facilities and an electrowinning tankhouse were built. The expansion makes Morenci the largest SX-EW facility in the world with the capacity for producing 372,000 t/yr (820 million pounds per year) of copper (Phelps Dodge Mining Co., 2001).

The U.S. Census Bureau reported 3.86 Mt of sulfuric acid was produced as a result of recycling spent and contaminated acid from petroleum alkylation and other processes (U.S. Census Bureau, 2001a, b, 2002a, b). This material was recycled by companies that produced acid for consumption in their own operations and also recycle acid used in their plants. The petroleum refining industry was believed to be the largest source and consumer of recycled acid for use in its alkylation process.

Stocks

Yearend inventories held by Frasch and recovered elemental sulfur producers increased to 232,000 t or about 12% more than that of 2000 (table 1). Based on apparent consumption of all forms of sulfur, combined yearend stocks amounted to about an 8-day supply, compared with a 6-day supply in 2000, a 12-day supply in 1999, a 7-day supply in 1998, and a 20-day supply in 1997. In 2000, yearend stocks were the lowest they had been since Frasch production became profitable early in the 20th century (Haynes, 1959, p. 61). Final stocks in 2001 represented 4% of the quantity held in inventories at the end of 1976 when sulfur stocks peaked at 5.65 Mt; this was a 7.4-month supply at that time (Shelton, 1978, p. 1296). In most cases, recovered sulfur producers found it difficult to accumulate any significant stockpiles. Many recovered operations did not have sufficient space for storing excess sulfur, and in many locations, environmental regulations did not allow stockpiling to occur. Without Frasch production, domestic sulfur stocks were expected to remain relatively stable.

Solid sulfur storage capacity in the United States was not high enough to allow a significant accumulation of stocks in oversupply situations. The only area for storing large quantities of excess sulfur was in Galveston, TX. Domestic recovered sulfur producers recognized the risks presented by the inability to find markets for their sulfur, and alternatives were being explored to avoid similar problems in the future. Installation of pelletizers were under consideration in Texas and on the Mississippi River. Permits for additional blocking capacity were being sought in Galveston. Additional molten storage tanks were being built on both sides of the Gulf of Mexico. Landfill disposal of sulfur was approved in New Mexico and western Texas, although this was not seen as a viable long-term option (d'Aquinn, 2001).

Prices

The contract prices for elemental sulfur at terminals in Tampa, FL, that are reported weekly in Green Markets, began the year at $63 to $66 per metric ton. Within a month, prices decreased to between $56 and $59 per ton and remained there until April when they dropped to between $41 and $44 per ton.

In an unprecedented move in mid-May, U.S. recovered sulfur producers in the Gulf Coast area offered to cut their sulfur price by $15 per ton retroactive to the first of May. Contract prices reached a low of from $26 to $29 per ton although spot prices were reported at more than $10 below that. U.S. producers were determined to maintain outlets for their products to maintain production of their primary products, natural gas and petroleum fuels. Lack of the ability to store unsold tonnage of sulfur can cause oil and gas processors to halt operations to limit sulfur accumulation. Significantly lower prices resulted in decreased Canadian imports caused by the less attractive pricing (Fertilizer Markets, 2001e). In October, prices started to inch back up and remained at $31 to $34 per ton through yearend.

Based on total shipments and value reported to the USGS, the average value of shipments for all elemental sulfur was estimated to be $10.11 per ton, which was 59% lower than that of 2000. Prices varied greatly on a regional basis, which caused the price discrepancies between Green Markets and the USGS. Tampa prices were usually the highest reported because of the large sulfur demand in the central Florida area. U.S. west coast prices were listed at $0 per ton, although in reality, west coast producers often faced negative values as a result of costs incurred at forming plants. These costs were necessary to make solid sulfur in acceptable forms, often known as prills, to be shipped overseas. The majority of west coast sulfur was sent to prillers who may have been subsidized by the refineries, and the formed sulfur was shipped overseas (Green Markets, 1999).

Foreign Trade

Exports of elemental sulfur from the United States, which included the U.S. Virgin Islands, as listed in table 7, were 11% lower in quantity than those of 2000 and 9% lower in value because the average unit value of U.S. export material increased slightly to $72.29. Exports from the west coast were 573,000 t, or 85% of total U.S. exports.

The United States continued to be a net importer of sulfur—imports of elemental sulfur exceeded exports by more than 1 Mt. Recovered elemental sulfur from Canada and Mexico delivered to U.S. terminals and consumers in the liquid phase furnished about 91% of all U.S. sulfur import requirements. Total elemental sulfur imports decreased by about 26% in quantity and by 44% in value; imports from Canada, mostly by rail, were 29% lower, and waterborne shipments from Mexico were 27% lower than those of 2000 (table 9). Imports from Venezuela were estimated to account for about 9% of all imported sulfur.

Although sulfur supplies were sufficient to meet demand, several Florida fertilizer companies continued to pursue necessary permits to build a terminal south of Tampa to handle formed sulfur to avoid future supply disruptions. After several unexpected delays late in 2000, Big Bend Transfer Station Co. (BBTC) (a joint venture of Cargill, CF Industries, and IMC Global Inc.) received from the Hillsborough County Commission approval for its sulfur melting plant south of Tampa early in 2001. The joint venture was formed to build a facility for remelting formed sulfur as a means of diversifying the companies' supply options. The project needed an air-quality permit from the county's Environmental Protection Commission. Upon successful completion of the permitting process, BBTC planned to install facilities for handling 1.5 million metric tons per year (Mt/yr) of sulfur with possible expansions to 2 Mt/yr (Green Markets, 2001a). This would enable BBTC to buy formed sulfur at the best prices available, perhaps from foreign producers.

BBTC experienced additional delays when a local environmental group challenged the zoning requirements in the State circuit court. The court ruled that BBTC must obtain a planned development zoning designation. The project will be presented to the same zoning officials that previously approved the project, thereby delaying construction of the project until sometime in 2002. During the years that legal requirements for construction had been pursued for the project, the supply situation for the central Florida market changed, thus placing the actual completion of the project in question (Green Markets, 2001b). BBTC project received final approval in March 2002. Completion was projected for early 2004, although questions remained as to whether the facility would actually be built (Green Markets, 2002).

In addition to elemental sulfur, the United States also had significant trade in sulfuric acid. Sulfuric acid exports were 10% higher than those of 2000 (table 8). Acid imports were almost seven times greater than exports (tables 8, 10). Canada and Mexico were the sources of 70% of U.S. 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 Europe and Japan. The tonnage of sulfuric acid imports was virtually the same as that of 2000, but the value of imported sulfuric acid increased by 24%.

World Review

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. Nondiscretionary sources represented 89% of the sulfur in all forms produced worldwide as listed in table 11.

Poland was the only country that produced more than 1 Mt of native sulfur by using either the Frasch or conventional mining methods (table 11). 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 was the only country in the top producers with more than 500,000 t of sulfur produced whose primary sulfur source was from pyrites. About 73% of world pyrites production was in China.

Of the 22 countries listed in table 11 that produced 500,000 t or more of sulfur, 15 obtained the majority of their production as recovered elemental sulfur. These 22 countries produced 91% of the total sulfur produced worldwide. The international sulfur trade was dominated by a limited number of exporting countries, which were, in descending order of importance, Canada, Saudi Arabia, Russia, the United Arab Emirates, Japan, and Germany; these countries exported more than 1 Mt of elemental sulfur each and accounted for 74% of total sulfur trade. Major sulfur importers, in descending order, were China, Morocco, India, the United States, Tunisia, and Brazil, all with imports of more than 1 Mt.

World production of sulfur was also slightly lower in 2001 than it was in 2000; consumption was believed to be also slightly lower. Statistics compiled by CRU International Ltd. showed 1998 to be the seventh consecutive year in which sulfur supplies exceeded demand (Kitto, 2000). Although complete data for 1999 through 2001 were not available, 2001 was assumed to represent the tenth consecutive year of excess sulfur supplies.

Prices in most of the world were believed to have averaged lower throughout the year but with a slight increase at yearend. Production of Frasch was 54% lower than that of 2000 as a result of termination of mining in the United States and the closure of one mine in Poland. Recovered sulfur production was virtually the same, and byproduct sulfuric acid production increased slightly compared with those of 2000. Supply continued to exceed demand; worldwide sulfur inventories increased, much of which was stockpiled in Canada. Globally, sulfur from pyrites decreased by 6%, much of which was a result of the continued decline in China and the construction of a sulfur-fired sulfuric acid plant in Spain to replace a pyrites-based plant.

Statistics compiled by the Oil & Gas Journal showed that the United States possessed 20% of the world's total refining capacity and 41% of the world's sulfur recovery capacity derived from oil refineries. The publication listed 732 oil refineries in 120 countries; only 55 of these countries were reported to have sulfur recovery capacity (Stell, 2001, p. 76, 78). Although the sulfur recovery data appeared to be incomplete, analysis of the data showed that most of the countries reporting no sulfur recovery at refineries were small with developing economies and limited refining industries. In general, as refining economies improve and the refining industries mature, additional efforts are made to improve sulfur recovery and atmospheric emissions.

Worldwide, sulfur levels in motor fuels were being cut. For example, near the end of 2001, the European Council voted on a proposal to require all diesel and gasoline sold in Europe to contain less than 10 ppm by the beginning of 2009, thus accelerating the previous deadline proposal by 2 years. European refiners have until 2005 to reduce sulfur levels to 50 ppm. The European Parliament will act on the legislation in 2002 (Sulphur, 2002a). Even before larger, more developed countries took action in this area, South Korea reduced the allowable sulfur in marine bunker fuels from 0.5% to 0.3%. The new standards must be met by July 2003 (Sulphur, 2001r). Marine bunker fuels are used to power most ocean-going vessels. The high-sulfur content of these fuels is believed to be a major contributor to high atmospheric sulfur dioxide levels near shipping lanes.

Canada.—For the first time, Canada surpassed the United States in sulfur production in all forms. It also led the world in the production of byproduct sulfur, exports of elemental sulfur, and stockpiled material. The majority of the sulfur production came from natural gas plants in Alberta where yearend sulfur inventories were estimated to be 14.3 Mt (PentaSul North America Sulphur Review, 2002).

Older natural gas operations in Alberta were facing the prospect of installing costly equipment to improve their sulfur recovery or closing if emissions regulations could not be met. In 1988, the Energy and Utilities Board (EUB) of Alberta enacted environmental legislation that covers emissions at natural gas operations in that Province. Facilities that did not meet the standards were given 15 years (until 2003) to upgrade their operations or shut down. In 2001, the deadline for compliance was extended until 2016 with incentives for early achievement. This covered 61 plants that release a total of 221 t/d of sulfur into the atmosphere. The cost of upgrading these plants was estimated to be nearly $227 million and will add 90 t/d to Canadian sulfur capacity. Voluntary reduction guidelines of 7.5% per year were set—plants that exceed these guidelines were eligible to bank the excess for future years (Sulphur, 2001a).

In addition to the large reserves of high-sulfur natural gas, Alberta has huge deposits of oil sands with estimated reserves of 300 million barrels of recoverable crude oil that also contain 4% to 5% sulfur (Stevens, 1998). As traditional petroleum production in Canada declined, oil sands became a more important source of petroleum for the North American market (Cunningham, 2001). Mining rights for all identified oil sands properties available in Alberta have been sold. Early in the year, about 1% of estimated oil sands had been extracted with plans for expansion at many of the operations being considered (Sulphur, 2001u).

Oil sands operations usually produce elemental sulfur, but one company was planning to produce another sulfur compound to be used in agriculture. In its expansion plans for its Mildred Lake oil sands upgrader in Alberta, Syncrude Canada Ltd. included a plant to produce fertilizer grade ammonium sulfate and 1,000 t/d of elemental sulfur. Syncrude planned to produce 100,000 t/yr of ammonium sulfate. The expansion should be complete in early 2004 (Sulphur, 2001p).

The Canadian Government established similar sulfur limits for motor fuels as the United States. Irving Oil Ltd., which was one of the first refiners to meet new Canadian fuel standards, spent Can$1 billion to upgrade its Saint Johns, New Brunswick, refinery to meet Canada's gasoline sulfur specifications that go into effect in 2005 (Goodwin, 2000). The new unit, which started production late in 2000, produced gasoline that met the upcoming 30-ppm sulfur standard and minimized octane loss (Gardner and Schwarz, 2001). As well as reducing sulfur in fuels, the upgrade was to reduce sulfur dioxide emissions at the refinery and to improve the reliability of environmental controls. Reductions in atmospheric sulfur dioxide emissions were self-imposed. The refinery already was in compliance with New Brunswick and Canadian regulations (Goodwin, 2000).

Chile.—The world's largest copper producer, Chile recovered nearly all its sulfur as byproduct sulfuric acid from copper smelting. As the country's smelters were modernized and new smelters installed, expectations were that sulfuric acid production would continue to increase as it has for the past few years. Consumption at copper leach operations was expanding also. Corporación Nacional Del Cobre (Codelco) completed the expansion to bring byproduct acid capacity to 700,000 t/yr at El Teniente (Sulphur, 2001f). In another move aimed at improving the value of the company and making copper leach operations more profitable, Codelco was planning to merge part of its Chuquicamata and other undeveloped deposits to share the leach facilities built to process the oxide ores (Sulphur, 2001g).

Noranda Inc. of Canada was completing engineering work and progressing with construction for expanding its Altonorte smelter to increase copper production by about 80%. Sulfuric acid production capacity, however, will nearly triple to 700,000 t/yr. The upgrade would make Altonorte more cost competitive and enable the company to capture 90% of the sulfur dioxide released by the smelter. The complete modernization project was expected to be completed in 2003 (Sulphur, 2001b, 2001k).

China.—Second only to the United States in sulfuric acid production, China produced almost 24 Mt of sulfuric acid in 2000, the most recent year for which data are available (Sulphur, 2002b). Although pyrites have been the mainstay of acid production, efforts were being made to change that. One of the few countries whose primary domestic source of sulfur was pyrites, China continued converting much of its sulfuric acid capacity from pyrites burning to elemental sulfur. Some new elemental sulfur-based acid plants were built, but much of the conversion was through adapting existing pyrites operations to use solid sulfur. The conversions were driven by economic and environmental concerns (Fertilizer Markets, 1999). In 2000, about one-third of the sulfuric acid produced in China was from elemental sulfur burning (Sulphur, 2002b).

Environmental awareness is a relatively recent concern in official Government considerations. Pyrites-based sulfuric acid plants in China emitted sulfur dioxide and other pollutants to the atmosphere, discharged pollutants to rivers, contaminated ground water, and presented solid waste disposal problems. A properly operated sulfur burner has very limited atmospheric emissions, no water discharge, and no solid waste issues (Sears, 2000). Canadian sulfur producers were instrumental in developing the elemental sulfur market in China but recently began to lose market share in China. Middle Eastern material was beginning to make inroads into the Canadian dominance in the Chinese market (Fertilizer Markets, 2001d).

The Chinese petroleum industry was working to modernize its facilities to reduce sulfur emissions as it increased imports of sour crudes from the Middle East. Chinese crude petroleum was relatively sweet, and imports have been sweet crudes because of the country's inadequate sulfur recovery capabilities. Work was progressing to improve sulfur recovery units at several refineries. Additional improvements at smelters were expected to increase availability of byproduct acid (Sears, 2000). Joint ventures with major oil producers willing to make investments in the Chinese industry were a large part of the strategy for reducing imports of oil products and improving the refining technology (Cunningham, 1999a).

Germany.—As one of the largest sulfur-producing countries in Europe, discrepancies existed between official Government production statistics and other sources reporting German production. Other sources showed German production significantly higher than Government sources with nearly 1 Mt more production of sulfur in all forms than official data. Most German sulfur was sold in European Union markets.

Iraq.—Questions remain about Frasch and other sulfur production in Iraq. Before Iraq invaded Kuwait, thus precipitating Operation Desert Shield in 1990 and Operation Desert Storm (the Gulf War) in 1991, Frasch production at the Mishraq Mine was around 1 Mt/yr with plans to expand capacity to 2 Mt/yr. Some recovered sulfur was also produced in Iraq. With the imposition of economic sanctions by the United Nations (UN) and very limited public information of any kind coming from Iraq, little is known of sulfur production in that country. Mishraq was not believed to be damaged during the war and could be operating at or near capacity, although that scenario is doubtful. The most likely situation is that Mishraq has produced consistently since 1990 but at a greatly reduced rate. Recovered sulfur production probably continued. With little outlet for any products as a result of the sanctions, significant stocks of sulfur are believed to have accumulated at Mishraq since the imposition of sanctions. Sulfur also was produced at two sour gas processing plants at Kirkuk and Beiji (Fertilizer Markets, 2000a).

Iraq reached an agreement with Jordan to supply all Jordan's sulfur requirements starting in late 2000 and through 2001. UN sanctions against Iraq have banned most trade with Iraq since it invaded Kuwait in 1990. Jordan invoked an article of the UN charter that allows a UN member state to refrain from implementing a sanction if it is against it's domestic interests. The price of the Iraqi sulfur, probably from the Mishraq frasch mine, was estimated to be nearly one-third less than similar material from elsewhere in the Middle East (Sulphur, 2000a). Jordan received 150,000 t of sulfur from Iraq in 2000; up to 1 Mt was expected in 2001 (Fertilizer Markets, 2000a).

Kazakhstan.—The Tengiz oilfield and gasfield is the main source of current (2001) sulfur production in Kazakhstan. Located on the northeastern shore of the Caspian Sea in western Kazakhstan, Tengiz has been operated by Tengizchevroil (TCO) since 1993. In 2000, Chevron Corp. raised its stake in TCO to 50%. Other owners in TCO were Kazakhoil (Kazakhstan's national oil and gas company) (20%), ExxonMobil (25%), and LUKARCO (a joint venture between BP and Russian oil company LUKoil) (5%) (Chevron Corp., 2000). One of the world's largest oilfields, Tengiz contains high-quality oil with 0.49% sulfur and associated natural gas that contains 12.5% hydrogen sulfide (Connell and others, 2000).

In August, the completion of a petroleum pipeline to carry crude oil from Tengiz to the Russian port of Novorossiysk on the Black Sea opened the first major route for carrying Tengiz light sweet oil to international markets. With this development and other transport routes for further exports, plans were laid for increased output of all products, which included sulfur, by up to 80% (Sulphur, 2002b). Production at Tengiz was estimated to be more than 1.2 Mt/yr with expectations for it to rise to 2.0 Mt in 2005 and 3.75 Mt by 2010 (Sulfur, 2001s).

Because of its remote location, little of the sulfur that has been produced at Tengiz since production began has been sold. TCO accumulated stocks of 4.6 Mt of elemental sulfur, which was 1.6 Mt more than the company had approval to store. TCO was planning the installation of sulfur forming equipment to enable easier transportation of sulfur to market (Sulphur, 2001v). The operators of Tengiz have considered reinjecting the acid gas into the formation, but the high reservoir pressures make this difficult with current (2001) technology (Sulfur, 2001s). The reinjection project would limit the growth of sulfur production to a total of about 2 Mt/yr (Sulphur, 2002b).

Sulfur also is recovered from the Karachaganak gas-condensate field in Kazakhstan near the Russian border. Because it is close to the Russian gas processing operation in Orenburg, sour gas from Karachaganak is treated at Orenberg. No gas treatment facilities have been installed at that site in Kazakhstan (Sulfur, 2001s).

Oil refineries are part of the plan for development for the Kashagan field offshore of Kazakhstan in the Caspian Sea. Sulfur production was expected to be about 1 Mt from the associated sour gas that will be separated from the crude oil. Commercial production is scheduled to begin in 2005 (Sulphur, 2002d).

Mexico.—A former Frasch producer, Mexico was the second largest supplier of imported recovered sulfur to the United States; the country produced Frasch sulfur from 1954 when mining began at San Cristobal until 1993 when the Texistepec Mine closed (Larson and Marks, 1955, p. 1136-1137). Mexico recovered most of its sulfur from its petroleum refineries and recovered byproduct sulfuric acid at its smelters.

Although Mexico produced about 5% of global crude oil, it did not have the refinery capacity to meet domestic demand for gasoline. The completion of the refinery upgrade at Pemex's Cadereyta refinery in 2000 brought capacity close to demand. Five additional upgrade projects were underway to transform the country's trade balance for gasoline. Mexican refineries were unable to process heavy maya crude into sufficient quantities of motor fuels. Pemex invested in U.S. refineries in Texas to ensure steady markets for their crude oil but were unable to find the capital to modernize its own refineries. Revamping at Cadereyta expanded capacity for diesel, jet fuel, and gasoline. Sulfur production was expected to be about 480 t/d with further expansion of 80 t/d and eventually reaching about 450,000 t/yr. Other planned modernization projects include those of Minatitlan, Salamanca, Salina Cruz, and Tula. No details on progress or expected sulfur recovery capacities were available. Additional sulfur supplies, perhaps more than 500,000 t/yr from a single project, were expected from new natural gas processing operations (Cunningham, 2000a).

Pemex had long-term supply contracts with U.S. refiners ExxonMobil, Marathon Ashland Petroleum LLC, and Premcor Inc. (Cunningham, 1999b). Pemex's joint venture with Shell at Deer Park, TX, completed its upgrade in 2001 (Sulphur, 2001l).

Poland.—During the year, one of Poland's two remaining sulfur mines closed. Operating since 1967, Poland's Jeziorko Mine at Tarnobrzeg was forced to close in response to decreasing demand for mined sulfur. At its peak of operation in the 1980s, Jeziorko produced more than 3.3 Mt/yr and set a record of 3.39 Mt in 1984 and 1988. In recent years, capacity was closer to 1 Mt/yr, although large resources remain (Sulphur, 2001q). The 800,000 t/yr capacity Osiek Mine continued to operate.

Poland exported more than 700,000 t of sulfur in 2000, most of which went to Morocco and some European countries. Osiek was designed with the potential for future expansion to 1.3 Mt (Fertilizer Week, 2001a). Oil refineries in Poland were upgrading their sulfur recovery units to meet air-quality regulations that forbid the release of sulfur dioxide into the atmosphere (Sulphur, 1999b). Even with the closure of Jeziorko, recovered sulfur remained a secondary source of sulfur in Poland.

Russia.—The Astrakhan Gas Processing Plant was the largest single source of recovered sulfur in the world. Construction by Astrakhangazprom's gas processing plant began in 1981 with the first production in 1986; this gas was 26% hydrogen sulfide and more than 4,000 meters deep. Astrakhan produces gasoline, diesel, furnace fuel oil, kerosene, and liquified gas. Sulfur production has increased significantly since 1995 with the completion of subsequent phases of development. In 1995, production at this operation was 1.7 Mt of sulfur. By 2000, production had more than doubled to 3.8 Mt. Further increases are expected from the final phase of the operation that was completed at yearend. By 2004, production should reach 4.5 Mt (Sulfur, 2001s). By the middle of 2001, stocks at Astrakhan were almost 1.4 Mt, 500,000 t of which had been stockpiled during the first 6 months of the year (Fertilizer Week, 2001b).

Orenburg is another sour gas operation in Russia with sulfur recovery of about 800,000 t/yr. This operation declined in the 1980s, but the discovery of the large Karachaganak gas-condensate field nearby in Kazakhstan brought new supplies of sour gas to be treated. No gas treatment facilities have been installed at the Kazakhstan site. About 20% of the sulfur production at Orenburg is believed to have come from Karachaganak gas (Sulfur, 2001s). Russian exports were about 1.8 Mt in 2001. The 43% decrease from the previous year reflected the worldwide decrease in trade caused by weak demand and low prices. Morocco and Tunisia were Russia's largest customers. Russian sulfur has displaced material from Canada and the Middle East in important markets in North Africa.

To stop Russian pollution from a nickel smelter on the Kola Peninsula from causing environmental damage in Norway, the Norwegian Government was paying $30 million to Pechanganickel to finance improvements to emission controls to limit sulfur dioxide emissions at the smelter. The Nordic Investment Bank and Norilsk Nickel (Pechanganickel's parent company) will contribute an additional $70 million dollars for the environmental upgrades. Total emissions, which include sulfur dioxide and heavy metals, should be reduced by 90%, and sulfur dioxide emissions should be reduced to 13,000 t/yr from 150,000 t/yr. About 200,000 t/yr of sulfuric acid should be produced (Sulphur, 2001o).

Saudi Arabia.—All Saudi Arabia's sulfur production is recovered from oil refining and natural gas processing. As a large exporter, Saudi industry was effected by low international prices, which caused producers to stockpile material for the first time in 3 years. In February, 50,000 t was poured to block (Fertilizer Markets, 2001c).

Spain.—Europe's largest sulfuric acid plant, which had a capacity of 2,400 t/d, was completed early in 2001. The sulfur-burning plant, which is at Fertiberia's Huelva phosphoric acid plant, nearly doubled the acid capacity of the three pyrites roasters that it replaced. Fertiberia has become one of the largest purchasers of imported sulfur in Europe (Sulphur, 2001d).

Turkey.—Contrary to trends in the rest of the world that are reducing and eliminating the use of pyrites in sulfuric acid production, Eti Holdings of Ankara was building a pyrites-based sulfuric acid plant at Bandirma. The plant will produce 750 t/d of 100% acid and was expected to be in operation in May 2003 (Sulphur, 2001t).

Venezuela.—Venezuela's Orinoco Basin is one of the world's largest resources of crude oil. If recent developments in refining technology had not provided the means for upgrading the crude, then it could not have been developed (Sulphur, 2000c). Upgraded crude production from the Orinoco Basin could eventually result in the production of 8 Mt/yr of sulfur with about 5 Mt/yr of that being produced in Venezuela and the rest at refineries in other countries, very possibly in the United States (Cunningham, 2000b).

Construction of heavy oil upgrading facilities at the port of José progressed. Petrozuata's heavy oil upgrader was the first of four planned projects at the José complex to upgrade Orinoco crudes and opened in February; Petrozuata was a joint venture between Conoco Inc. and PdVSA. The coking technology at this 145-t/d-capacity operation did not produce huge quantities of sulfur. Most of the sulfur remains in the coke product. Other projects in Venezuela produce significantly more sulfur during the upgrading process (Sulphur, 2001n).

Sincor [an alliance of TotalFinaElf (47%), PdVSA (38%), and Statoil AS (15%)] was the second completed upgrade operation. Its crude oil production facilities in the Orinoco Belt opened in February with expectations for upgraded oil to be available for sale from its José upgrader in 2002. In addition to the light, sweet crude, the company will also produce coke and sulfur. Of the four projects under development based on extra-heavy sour crudes from Orinoco, the Sincor crude will be the lightest and have the lowest sulfur content. Sulfur production was designed to recover 900 t/d (Chang, 2001).

The Cerro Negro project (ExxonMobil, PdVSA, and Veba Oel AG of Germany) was the third facility (Sulphur, 2001m). Upgraded crude oil was shipped for the first time from this operation to the United States in August. The fourth project, the Hamaca joint venture (PdVSA, Phillips, and Texaco), received go-ahead funding. It will pipe heavy oil to José for upgrading (Sulphur, 2001i). Once these heavy oil upgrading projects are completed at José, the terminal will provide an additional 400,000 t/yr of sulfur to the world market (Sulphur, 2000b).

PdVSA also is involved in a joint venture for processing Venezuelan crude at the Phillips refinery in Sweeny, TX. PdVSA and Phillips spent $540 million to build a coker and a vacuum distillation unit to be operated by Merey Sweeny Limited Partnership (Sulphur, 2001j).

International financing for additional projects involving Orinoco crudes may be more difficult to obtain in the future. A new law was passed that could limit outside interest in further development of these projects. The law includes a 30% royalty rate and requires that PdVSA hold at least 50% of the equity in any new enterprise (Sulphur, 2002c).

Zambia.—First Quantum Minerals was expanding its sulfur-burning sulfuric acid plant at its Bwana Mkubwa operation to convert it to a copper SX-EW operation. Additional ore from the nearby Lonshi Mine in Congo (Kinshasa) will be processed (Sulphur, 2001e).

Current Research and Technology

Biodesulfurization.—The Shell-Paques/Thiopaq process was developed to remove sulfur from hydrogen sulfide found in high-pressure natural gas, synthesis gas, and refinery gas streams by using naturally occurring, harmless microorganisms as catalysts. Sulfur compounds are dissolved in an aqueous solution and then treated in the bioreactor to produce either elemental sulfur or sulfate compounds. Hydrogen sulfide removal is 99.99%. The bioreactor, which can be built in limited space, operates at ambient conditions, thus allowing use of noncorroding construction materials. Use of polypropylene and polyethylene pipes and valves results in long equipment life. These units require little attention from operators and no shutdowns for overhauls because all routine maintenance is possible while the unit is operating. In addition to its use in natural gas treatment and oil refining, Thiopaq can be used commercially in such industries as chemical processing, food processing, mining, pulp and paper, and wastewater. Current (2001) adaptations of the process can handle throughput of up to 45 t/d (Sulphur, 2001c).

Injection of Sulfur Dioxide.—Because sulfur stockpiles continued to expand, Alberta Sulfur Research Ltd. (ASR) was investigating the possibility of using a process for reinjecting sulfur into a sour gas reserve to dispose of unwanted sulfur and using the heat produced to generate electrical power. Sulfur would be burned to produce sulfur dioxide that would be injected into the reservoir under moderate pressure, and then react with the hydrogen sulfide to form elemental sulfur that would fall to the bottom of the reservoir. The sulfur-forming reaction would reduce the pressure of the reservoir, thus decreasing the concern that reinjected materials would escape into the atmosphere. Eighteen months of laboratory research has supported the theory. ASR planned a pilot study for further verification of the proposal (Clark, 2001a).

Reinjection of Hydrogen Sulfide.—Reinjection of the sulfur as hydrogen sulfide into an appropriate underground reservoir was an attractive alternative in some instances at some natural gas operations but was seldom feasible at oil refineries. In acid gas reinjection from sour gas processing, the hydrogen sulfide and carbon dioxide were separated from the gas by using standard separation techniques and recompressed into a suitable injection zone. The suitability of the injection zone was influenced by its distance from the processing facility and could be a large aquifer, a depleted reservoir, or a zone that produces sour fluids. A depleted reservoir was especially attractive because its size and original pressure were already known, which made the determination of its holding capacity easier to determine. The sour gases also could be reinjected into a producing deposit.

Reinjection was being used at many small-scale operations, especially in Canada, but it had not been demonstrated to work on a large scale. Preventing the migration of reinjected gases from the reservoir into adjacent reservoirs or aquifers or into the atmosphere through an outcrop was essential for successful implementation.

With large-scale reinjection schemes, the energy balance would be an important factor in determining its feasibility. Without the sulfur recovery plant that produces energy, which can be used elsewhere in the operation, steam production by using an external energy source, such as natural gas or electricity, was required. Using natural gas presented the unusual situation of producing carbon dioxide emissions to reinject carbon dioxide. A determination was needed of whether the environmental benefit of reinjecting carbon dioxide was canceled out by the carbon dioxide emissions produced for that reinjection.

A feasibility study conducted by Abu Dhabi National Oil Company showed that a large-scale reinjection project could have a favorable balance between energy consumption and greenhouse gas emissions. The technical and operating challenges were yet to be resolved (Connock, 2001).

Underground Storage.—Alberta Sulphur Research Ltd. was analyzing preliminary data from its 5-year test for storing elemental sulfur underground. The expenses incurred to mitigate the cost of acid run-off treatment from sulfur stored in large blocks, such as found in Alberta, can be as much as $10 million per year for a 3-Mt block. Storing the sulfur underground in areas with low subsoil temperatures inhibits the action of the bacteria that converts the elemental sulfur to sulfuric acid by maintaining temperatures lower than necessary for bacterial activity and restricting the available oxygen required for the activity. Data from the first 2 years of the test showed no bacterial activity. The 5-year test was expected to provide support for regulatory approval for this type of sulfur storage (Clark, 2001b).

Outlook

The sulfur industry continued on its path of increased production, slower growth in consumption, higher stocks, and expanded world trade. U.S. production from petroleum refineries is expected to increase substantially in the next few years as expansions, upgrades, and new facilities at existing refineries are completed, thus enabling refiners to increase throughput of crude oil and to process higher sulfur crudes. Projects at oil refineries with resultant expansions of sulfur recovery facilities in Louisiana and Texas completed late in 2000 and during 2001 resulted in an additional capacity of 540,000 t/yr. An expected operating rate of about 80% represents an additional supply of 430,000 t/yr (Wilkinson, 2001). Production from natural gas operations varies but is usually between 2.0 and 2.2 Mt/yr, although recent years have seen a downward trend. Output is expected to average around 2 Mt/yr.

Worldwide recovered sulfur output should continue to increase. The largest increases in recovered sulfur production through 2005 should come from the Middle East's and Russia's growth in sulfur recovery from natural gas, Canada's expanded oil sands operations, and Asia's improved sulfur recovery at oil refineries (Kennedy, 2001). Refineries in developing countries should begin to improve environmental protection measures and eventually approach the environmental standards of plants in Japan, North America, and Western Europe.

Experts from the natural gas industry estimate that the world demand for natural gas will grow by 2.5% per year during the next 20 years for a total 50% increase in demand. Producing 50% more gas means recovering at least an additional 50% in sulfur from that source. Future gas production, however, is likely to come from deeper, hotter, and sourer 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 depressed in the United States as long as the copper smelters remain idle. With the copper industry's switch to lower cost production processes and producing regions, the three idle smelters may never reopen. Worldwide, the outlook is different. Because copper production costs in many countries are lower than in the United States, acid production from those countries has not decreased as drastically, and increased production is more likely. Environmental controls were less of a concern in developing countries in the past. Many copper producers in these and even in developed countries, however, are installing more-efficient sulfuric acid plants to limit sulfur dioxide emissions at new and existing smelters. Planned and in-progress improvement projects could increase byproduct acid production to 52 Mt by 2010 or the equivalent of about 17 Mt of sulfur from an estimated 11.6 Mt (3.8 Mt of sulfur) in 2001 (Sulphur, 1999a).

Frasch and pyrites production, however, have little chance of significant long-term increases, even after the completion of the pyrites burner in Turkey. 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 closure of the Polish sulfur mine. Frasch sulfur 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. World sulfur demand for fertilizer is forecast to increase at about 1.9% per year for the next 10 years; industrial demand is predicted to grow at 2.3% 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 most sulfur is consumed, is projected to increase about by 1.8% per year through 2010. With new and expanding phosphate fertilizer capacity in Australia, China, and India, sulfur demand will grow in these areas at the expense of some phosphate operations elsewhere, thus transferring sulfur demand rather than creating new. 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. China and India are primary markets for U.S. 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 producers will be competing for those markets.

Use of sulfur directly or in compounds as fertilizer should 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 be significant; thus far, however, growth has been slow.

Industrial sulfur consumption has more prospects for growth than in recent years, but still not enough to consume all projected surplus production. Conversion to or increases in copper leaching by producers who require significantly more sulfuric acid for the leaching operations than was used in 2001 bode well for the sulfur industry. Nickel pressure acid leach operations were demanding increased quantities of sulfur. 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. Estimates show sulfur production exceeding consumption by 3 Mt/yr for the next 20 years and worldwide inventories reaching 80 Mt by 2020 (Hyne, 1999). The potential exists for involuntary sulfur production of 80 to 100 Mt/yr by 2050; this represents a substantial increase in the time period that could be required to develop viable energy alternatives to fossil fuels (Cunningham, 2000b)

Unless significant new uses for elemental sulfur are implemented, 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-traditional products, but their use so far has been very limited. Interest in these materials seemed to be increasing but only in additional research. No large-scale projects were announced that would require sizable quantities of sulfur. These proposals may have to be revisited to avoid building mountains of sulfur in the not-too-distant future.

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TABLE 1
SALIENT SULFUR STATISTICS 1/

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

	1997	1998	1999	2000	2001
United States:					
Production:					
Frasch	2,820 e/	1,800 e/	1,780 e/	900 e/	--
Recovered 2/	7,650	8,220	8,220	8,380	8,270
Other	1,550	1,610	1,320	1,030	982
Total e/	12,000	11,600	11,300	10,300	9,250
Shipments:					
Frasch	W	W	W	W	--
Recovered 2/	10,400 3/	10,500 3/	9,800 3/	9,500 3/	8,250
Other	1,550	1,610	1,320	1,030	982
Total e/	11,900	12,100	11,100	10,500	9,240
Exports:					
Elemental 4/	703	889	685	762	675
Sulfuric acid	39	51	51	62	69
Imports:					
Elemental	2,060	2,270	2,580	2,330	1,730
Sulfuric acid	659	668	447	463	462
Consumption, all forms	13,900	14,100	13,400	12,500	10,700
Stocks, December 31, producer, Frash and recovered	761	283	451	208	232
Value:					
Shipments, free on board (f.o.b.) mine or plant:					
Frasch	W	W	W	W	--
Recovered 2/ 3/	$375,000	$306,000	$371,000	$239,000	$82,900 e/
Other	$98,100	$77,100	$66,400	$55,100	$49,500
Total	$473,000	$383,000	$437,000	$295,000	$132,000
Exports, elemental 5/	$36,000	$35,400	$35,800	$53,700	$48,800
Imports, elemental	$64,900	$58,400	$51,600	$39,400	$22,100
Price, elemental, f.o.b. mine or plant dollars per metric ton	$36.06	$29.14	$37.81	$24.73	$10.11 e/
World, production, all forms (including pyrites)	56,900 r/	57,200 r/	57,800 r/	58,100 e/	57,300 e/

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; included with "Recovered." -- 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 corresponding Frasch sulfur data.
4/ Includes exports from the U.S. Virgin Islands to foreign countries.
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)

	2000			2001		
		Shipments			Shipments	
State	Production	Quantity	Value	Production	Quantity	Value e/
Alabama	320	321	7,970	304	301	2,240
California	1,150	1,140	5,660	963	951	2,280
Illinois	444	444	5,900	436	437	837
Louisiana	1,070	2,180 2/	W	1,100	1,100	12,800
Michigan and Minnesota	34	34	483	35	36	176
Mississippi	525	533	20,100	559	551	22,200
New Mexico	48	48	(3/)	49	49	(3/)
North Dakota	50	50	(3/)	56	56	(3/)
Ohio	112	111	2,210	112	113	554
Texas	2,760	2,770	80,300 2/	2,740	2,740	36,700
Washington	113	110	27	102	102	(3/)
Wyoming	1,030	1,030	16,900	1,110	1,120	6,590
Other 4/	717	730	99,800	699	694	(1,480)
Total	8,380	9,500	239,000	8,270	8,250	82,900

See footnotes at end of table.

TABLE 2--Continued
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE 1/

e/ Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Includes corresponding Frasch sulfur data.
3/ Some sulfur producers in this State incur expenses to make their production available to consumers.
4/ Includes Arkansas, Colorado, Delaware, Florida, Indiana, Kansas, Kentucky, Louisiana (value in 2000), Montana, New Jersey, 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 DISTRICT 1/

(Thousand metric tons)

	2000		2001	
District and source	Production	Shipments	Production	Shipments
Petroleum administration for defense district (PAD) 1:				
Petroleum and coke	240	246	187	187
Natural gas	43	42	37	37
Total	283	288	224	225
PAD 2:				
Petroleum and coke	882	882	900	902
Natural gas	53	53	58	58
Total	935	935	958	960
PAD 3: 2/				
Petroleum	3,890	W	4,200	4,180
Natural gas	904	W	665	663
Total	4,800	5,940 3/	4,860	4,840
PAD 4 and 5:				
Petroleum	1,340	1,320	1,200	1,190
Natural gas	1,020	1,020	1,030	1,040
Total	2,360	2,340	2,230	2,230
Total petroleum and coke	6,360	W	6,480	6,460
Total natural gas	2,020	W	1,790	1,800
Grand total	8,380	9,500 3/	8,270	8,250

W Withheld to avoid disclosing company proprietary data.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Includes the U.S. Virgin Islands.
3/ Includes corresponding Frasch sulfur data.

TABLE 4
BYPRODUCT SULFURIC ACID PRODUCED
IN THE UNITED STATES 1/ 2/

(Thousand metric tons, sulfur content, and thousand dollars)

Type of plant	2000	2001
Copper 3/	830	813
Zinc 4/	123	122
Lead and molybdenum 4/	73	47
Total	1,030	982
Value	$55,100	$49,500

1/ Includes 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/

(Thousand metric tons)

	2000	2001
Total elemental:		
Shipments 3/	9,500	8,250
Exports	762	675
Imports	2,330	1,730
Total	11,100	9,300
Byproduct sulfuric acid:		
Shipments 3/	1,030	982
Exports 4/	62	69
Imports 4/	463	462
Grand total	12,500	10,700

1/ Crude sulfur or sulfur content.
2/ Data are rounded to no more than three significant digits; may not add to totals shown.
3/ Includes the U.S. Virgin Islands.
4/ 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, sulfur content)

		Elemental sulfur 2/		Sulfuric acid (sulfur equivalent)		Total	
SIC 3/	End use	2000	2001	2000	2001	2000	2001
102	Copper ores	--	--	671	691	671	691
1094	Uranium and vanadium ores	--	--	2	3	2	3
10	Other ores	--	--	44	26	44	26
26, 261	Pulpmills and paper products	W	--	136	194	136	194
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products 4/	75 r/	W	152	158	227 r/	158
281	Other inorganic chemicals	W	W	202	207	202	207
282, 2822	Synthetic rubber and other plastic materials and synthetics	--	--	68	68	68	68
2823	Cellulosic fibers, including rayon	--	--	5	11	5	11
283	Drugs	--	--	2	3	2	3
284	Soaps and detergents	W	W	1	7	1	7
286	Industrial organic chemicals	--	--	82	86	82	86
2873	Nitrogenous fertilizers	--	--	213	188	213	188
2874	Phosphatic fertilizers	--	--	7,110	6,840	7,110	6,840
2879	Pesticides	--	--	14	10	14	10
287	Other agricultural chemicals	1,260	1,120	29	31	1,290	1,150
2892	Explosives	--	--	8	10	8	10
2899	Water-treating compounds	--	--	52	66	52	66
28	Other chemical products	--	--	22	21	22	21
29, 291	Petroleum refining and other petroleum and coal products	1,460	1,960	497	591	1,960	2,550
331	Steel pickling	--	--	16	17	16	17
333	Nonferrous metals	--	--	38	38	38	38
33	Other primary metals	--	--	8	5	8	5
3691	Storage batteries (acid)	--	--	11	13	11	13
	Exported sulfuric acid	--	--	6	2	6	2
	Total identified	2,790	3,080	9,390	9,280	12,200	12,400
	Unidentified	1,190	1,750	237	250	1,430	2,000
	Grand total	3,980	4,830	9,620	9,530	13,600	14,400

r/ Revised. 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 and paints and allied products.

TABLE 7
U.S. EXPORTS OF ELEMENTAL SULFUR, BY COUNTRY 1/ 2/

(Thousand metric tons and thousand dollars)

Country	2000 Quantity	2000 Value	2001 Quantity	2001 Value
Australia	(3/)	6	(3/)	152
Brazil	115	3,780	179	4,570
Canada	46	5,300	52	5,740
Korea, Republic of	5	6,860	9	6,920
Mexico	178	13,100	155	7,120
Morocco	210	6,040	75	3,390
Senegal	126	5,910	66	2,320
Other	82	12,700 r/	139	18,600
Total	762	53,700	675	48,800

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.
3/ Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 8
U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY 1/

Country	2000 Quantity (metric tons)	2000 Value (thousands)	2001 Quantity (metric tons)	2001 Value (thousands)
Canada	154,000	$7,890	159,000	$8,380
China	5,080	1,240	788	837
Dominican Republic	2,760	318	531	95
Israel	349	469	2,630	818
Japan	2,130	324	115	159
Korea, Republic of	45	44	59	153
Mexico	3,850	589	3,240	490
Netherlands	658	104	2	9
Netherlands Antilles	--	--	67	63
Panama	22	13	--	--
Saudi Arabia	430	774	2,210	778
Singapore	777	594	241	207
Taiwan	950	422	485	297
Trinidad and Tobago	4,120	347	6,280	565
United Kingdom	880	99	1,860	115
Venezuela	787	90	3	9
Other	13,300	2,470	31,900	2,960
Total	191,000	15,800	210,000	15,900

-- 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)

Country	2000 Quantity	2000 Value 2/	2001 Quantity	2001 Value 2/
Canada	1,690	10,900	1,210	7,060
Mexico	489	19,200	359	8,400
Other	151	9,300	161	6,600
Total	2,330	39,400	1,730	22,100

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, as adjusted by the U.S. Geological Survey.

TABLE 10
U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY 1/

Country	2000 Quantity (metric tons)	2000 Value 2/ (thousands)	2001 Quantity (metric tons)	2001 Value 2/ (thousands)
Canada	803,000	$24,300	525,000	$17,800
Germany	24,000	926	37,100	1,900
Japan	97,300	6,040	47,200	2,510
Mexico	328,000	8,720	458,000	16,500
Spain	16,400	478	41,500	968
Other	148,000	1,050	306,000	11,800
Total	1,420,000	41,500	1,410,000	51,500

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/	1997	1998	1999	2000	2001 e/
Australia, byproduct: e/					
Metallurgy	474	507	441	654	675
Petroleum	22 r/	22 r/	25 r/	30 r/	45
Total	496 r/	529 r/	466 r/	684 r/	720
Canada, byproduct:					
Metallurgy	1,072	1,153	1,156	1,167 r/	1,109 4/
Natural gas, petroleum, tar sands	8,408	8,541	8,960	8,779 r/	8,251 4/
Total	9,480	9,694	10,116	9,946 r/	9,360 4/
Chile, byproduct, metallurgy e/	768	899	1,040	1,100	1,160
China: e/					
Elemental	230 r/	230 r/	280 r/	290 r/	290
Pyrites	6,040	4,490	3,860	3,370	3,090
Byproduct, metallurgy	1,400	1,450	1,630 r/	1,900 r/	2,000
Total	7,670 r/	6,170 r/	5,770 r/	5,560 r/	5,380
Finland: e/					
Pyrites	373 4/	380 r/	380 r/	260 r/	270
Byproduct:					
Metallurgy	307 4/	296 4/	299 r/	283 r/	227
Petroleum	50 4/	45 r/	42 r/	46 r/	46
Total	730 4/	721 r/	721 r/	589 r/	543
France, byproduct: e/					
Natural gas	697 4/	600	600	600	600
Petroleum	263 4/	245	250	250	250
Unspecified	100	261	250	260	250
Total	1,060	1,110	1,100	1,110	1,100
Germany, byproduct: e/					
Metallurgy	25	25	25	30	30
Natural gas and petroleum	1,085 4/	1,100	1,100	1,110	1,110
Unspecified	50	50	60	100	100
Total	1,160	1,180	1,190	1,240	1,240
India: e/					
Pyrites	30 r/	40 r/	32 r/	32 r/	32
Byproduct:					
Metallurgy	131	196	261	359	458
Petroleum and natural gas	51 r/	60	101	376	451
Total	212 r/	296 r/	394 r/	767 r/	941
Iran, byproduct: e/					
Metallurgy	50	50	48	50	50
Natural gas and petroleum	815 r/	889 r/	963 r/	963 r/	933
Total	865 r/	939 r/	1,010 r/	1,010 r/	983

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/	1997	1998	1999	2000	2001 e/
Italy, byproduct: e/					
Metallurgy	229	199	193	203	203
Petroleum	380	425	485	490	540
Total	609	624	678 4/	693 4/	743
Japan:					
Pyrites e/	39	23	41	30	30
Byproduct:					
Metallurgy	1,339 r/	1,322	1,361 r/	1,384 r/	1,319 4/
Petroleum	2,013	2,083	2,060	2,072 r/	2,025 4/
Total	3,391 r/	3,428	3,462 r/	3,486 r/	3,374 4/
Kazakhstan, byproduct: e/					
Metallurgy	139	212	245	300	300
Natural gas and petroleum	778	933	1,070	1,200	1,400
Total	917	1,150	1,320	1,500	1,700
Korea, Republic of, byproduct: e/					
Metallurgy	338 r/	476 r/	528 r/	572 r/	665
Petroleum	600 r/	600 r/	600 r/	600 r/	600
Total	938 r/	1,080 r/	1,130 r/	1,170 r/	1,270
Kuwait, byproduct, natural gas and petroleum e/	625 r/	650 r/	639 r/	512 r/	524
Mexico, byproduct:					
Metallurgy	417	474	474 r/	474 r/	572
Natural gas and petroleum	923	913	860	851 r/	878 4/
Total	1,340	1,387	1,334 r/	1,325 r/	1,450
Netherlands, byproduct: e/					
Metallurgy	127	131	129	123 r/	126
Petroleum	450	432	445	428 4/	384
Total	577	563	574	551 r/	510
Poland: 5/					
Frasch	1,673	1,345 r/	1,172 r/	1,482 r/	1,076 4/
Byproduct: e/					
Metallurgy	256	260	278 r/ 4/	261 r/ 4/	273
Petroleum	44	60 r/ 4/	74	70	70
Gypsum e/	12	10	--	--	--
Total	1,985	1,675 r/	1,524 r/	1,813 r/	1,420
Russia: e/ 6/					
Native	50	50	50	50	50
Pyrites	400	254	300	350	400
Byproduct, natural gas	2,950	3,940	4,410	4,900	5,300
Other	350	411	510	600	500
Total	3,750	4,650	5,270	5,900	6,250
Saudi Arabia, byproduct, all sources	1,750 r/	2,050 r/	1,940 r/	2,101 r/	2,350
Spain:					
Pyrites	424	430	388	138 r/	71
Byproduct: e/					
Coal (lignite) gasification	2	2	2	1	1
Metallurgy	456	461	455	454	450
Petroleum	85	100	110	115	100
Total e/	967	993	955	708 r/	622
United Arab Emirates, byproducts, natural gas and petroleum e/	967	967	1,089 4/	1,120	1,490
United States:					
Frasch e/	2,820	1,800	1,780	900	-- 4/
Byproduct:					
Metallurgy	1,550	1,610	1,320	1,030	982 4/
Natural gas	2,420	2,160	2,010	2,020	1,790 4/
Petroleum	5,230	6,060	6,210	6,360	6,480 4/
Total e/	12,000	11,600	11,300	10,300 4/	9,250 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/	1997	1998	1999	2000	2001 e/
Other: e/ 7/					
Frasch	270 r/	275 r/	273 r/	249 r/	249
Native	171 r/	163 r/	146 r/	148 r/	148
Pyrites	460 r/	345 r/	349 r/	295 r/	315
Byproduct:					
Metallurgy	833 r/	937 r/	907 r/	950 r/	1,050
Natural gas	130	206	215	215 r/	210
Natural gas, petroleum, tar sands, undifferentiated	747 r/	886 r/	875 r/	869 r/	886
Petroleum	981 r/	878 r/	825 r/	889 r/	833
Unspecified	1,230 r/	1,290 r/	1,270 r/	1,370 r/	1,390
Total	4,820 r/	4,980 r/	4,860 r/	4,990 r/	5,070
Grand total	56,900 r/	57,200 r/	57,800 r/	58,100 r/	57,300
Of which:					
Frasch	4,510	3,170 r/	2,980 r/	2,410 r/	1,100
Native 8/	701 r/	693 r/	726 r/	713 r/	713
Pyrites	7,770 r/	5,960 r/	5,350 r/	4,480 r/	4,210
Byproduct:					
Coal (lignite) gasification e/	2	2	2	1	1
Metallurgy	9,910 r/	10,700 r/	10,800 r/	11,300 r/	11,600
Natural gas	6,200	6,900	7,230	7,740 r/	7,900
Natural gas, petroleum, tar sands, undifferentiated	14,400 r/	14,900 r/	15,700 r/	15,800 r/	15,900
Petroleum	9,960 r/	10,800 r/	11,000 r/	11,200 r/	11,200
Unspecified	3,480 r/	4,060 r/	4,029 r/	4,430 r/	4,590
Gypsum e/	12	10	--	--	--

e/ Estimated. 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 22, 2002.

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 the 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 origin 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.

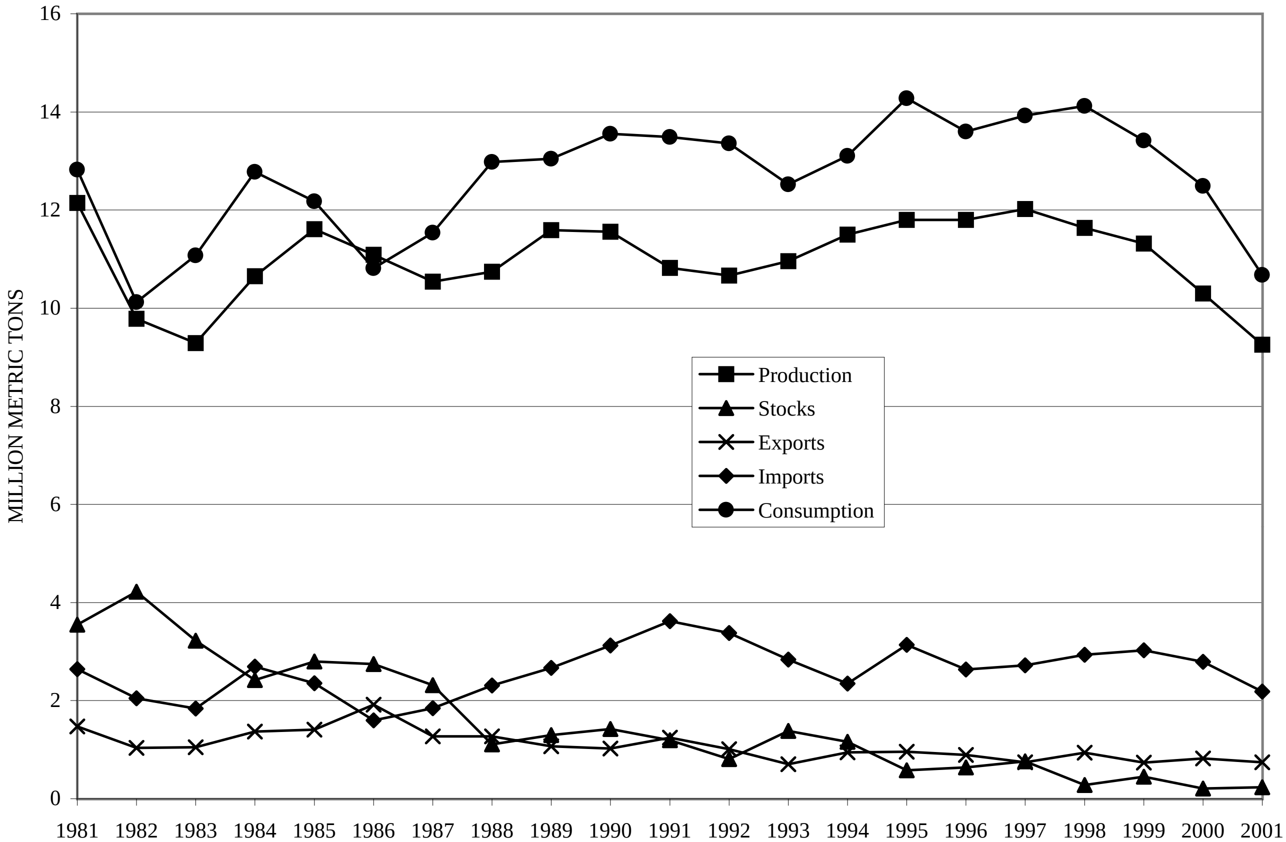
5/ Official Polish sources report total Frasch and native mined elemental sulfur output annually, undifferentiated; this figure has been divided between Frasch and other native sulfur on the basis of information obtained from supplementary sources.

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

7/ Includes all countries, except the above mentioned, as follows: Australia, Canada, Chile, China, Finland, France, Germany, India, Iran, Italy, Japan, Kazakhstan, Republic of Korea, Kuwait, Mexico, Netherlands, Poland, Russia, Saudi Arabia, Spain, United Arab Emirates, and United States.

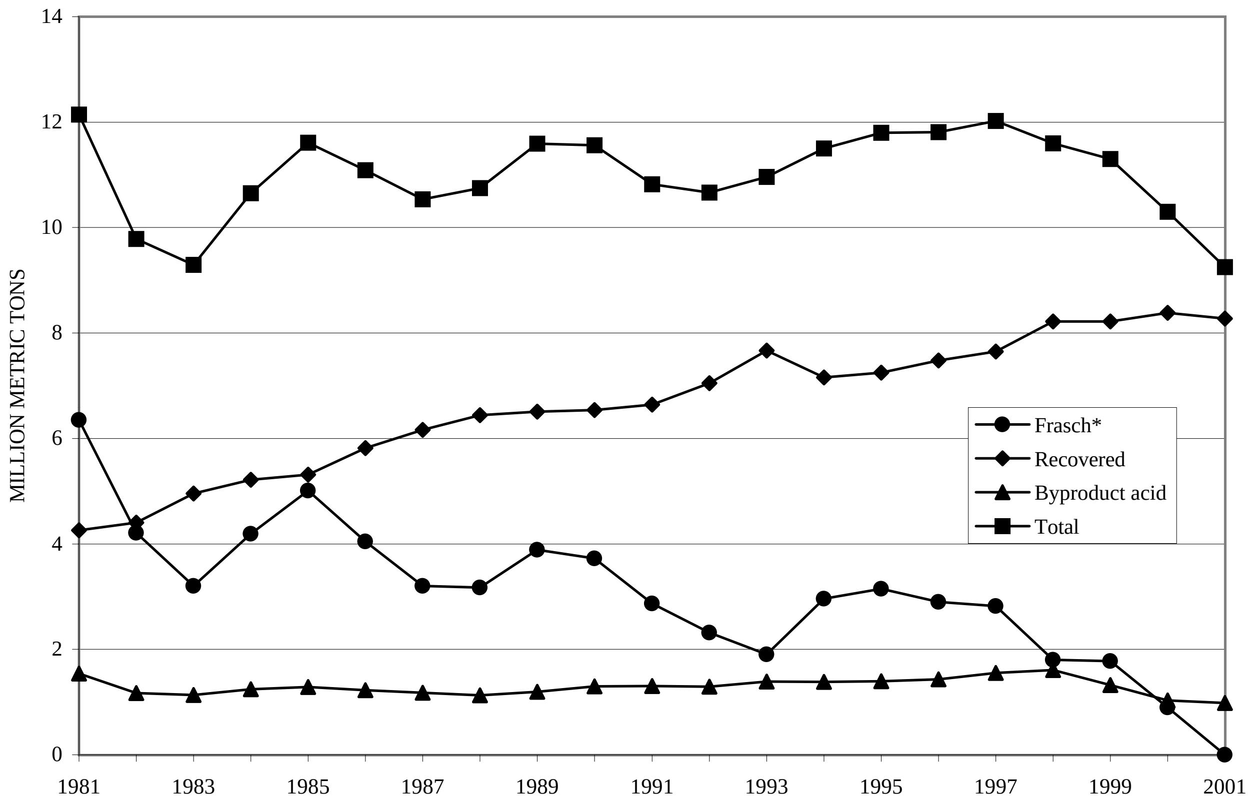
8/ Includes "China, elemental."

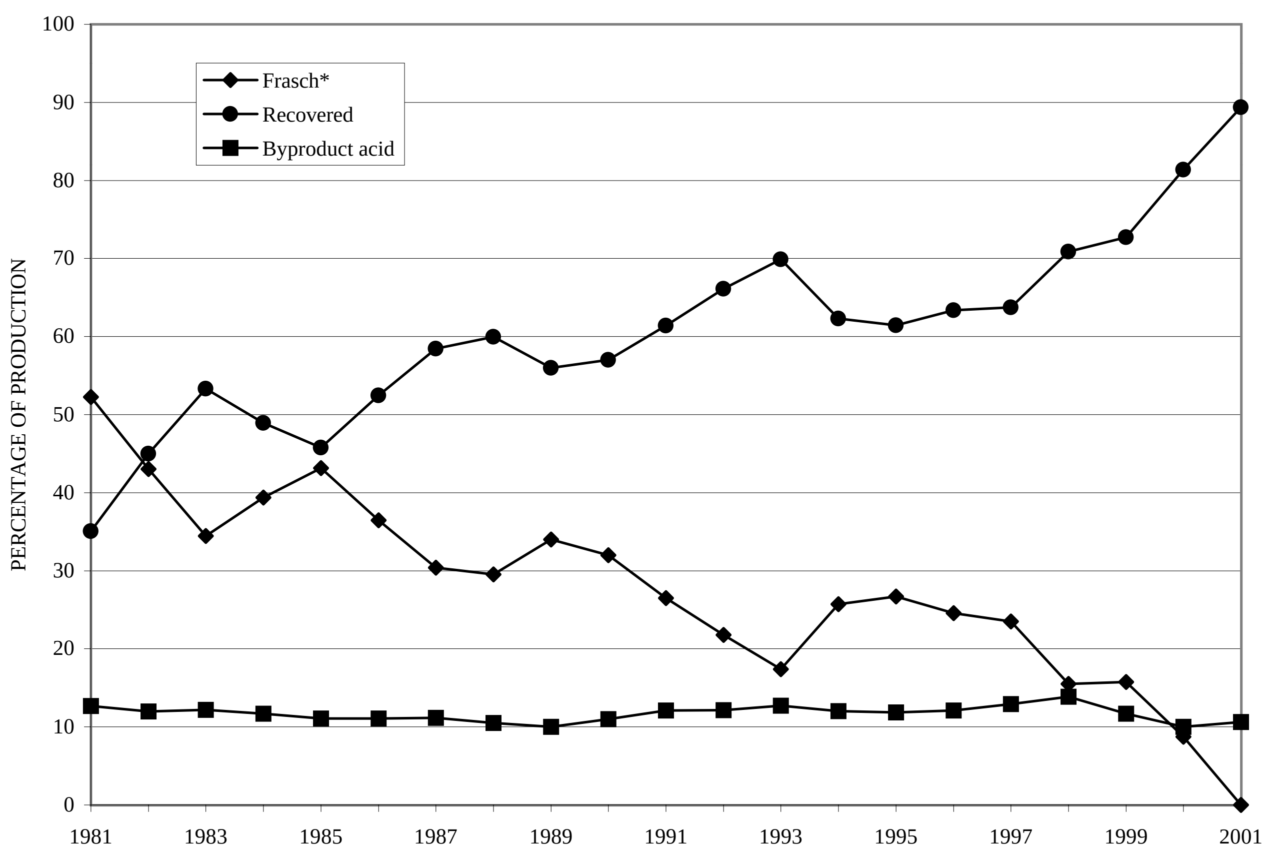
FIGURE 1
TRENDS IN THE SULFURE INDUSTRY IN THE UNITED STATES



Based on the average reported values for elemental sulfur (Frasch and recovered), free on board mine and/or plant, these prices reflect about 90% of the shipments of sulfur in all forms from 1981 through 2001.

FIGURE 2
TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES





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