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## GEOHERMAL SULFUR, MARKETING STRATEGIES

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### ABSTRACT

Sulfur is a necessary raw material for numerous industrial and agricultural products. Global projections suggest an annual 3.4% rise in elemental sulfur consumption over the next 10-15 years. The quality of sulfur varies with geography (Texas Bright/Louisiana Dark) and production techniques (hydrogen sulfide abatement). Sources of elemental sulfur at the Geysers in northern California are products of hydrogen sulfide abatement and constitute a significant waste stream volume that must be disposed typically by land filling at certified hazardous waste disposal sites. Recently enacted environmental legislation (land ban) coupled with waste minimization efforts in California have prompted the exploration of alternatives to land disposal for these waste streams. There are some variations in sulfur production rates and composition however, a market interest has currently been expressed. The preferred regulatory hierarchy of alternatives in California (source reduction, recycling and treatment) certainly affect current practices, marketing strategies for recycling and future opportunities within the complex environmental regulatory framework.

### INTRODUCTION

Sulfur, known as brimstone ("the stone that burns") ranks 13th in abundance among the elements in the earth's crust (0.06 wt%). Sulfur is one of the important native elements and is perhaps the most significant raw material used in almost every sector of the chemical industrial complex. Greater than 85% of the annual world sulfur consumption is converted to sulfuric acid or produced in that form (New Encyclopedia, 1973-74).

Sulfur was used by early man as a colorant for cave drawings, as a fumigant, in medicine and as incense. In 2000 B.C. the Egyptians used sulfur in bleaching linen textiles. The Romans combined brimstone with tar, pitch and other combustibles to produce the first incendiary weapons. Muslims from about 700 A.D. developed alchemy and were supposedly the first to produce sulfuric acid. Sulfur is a

main ingredient of gunpowder which was refined in China around the 10th century<sup>1</sup>. During the 14th century, gunpowder was introduced to Europe for use in warfare which made the mineral an important commodity. It was not until the birth of the science of chemistry in the 1700's and the rise of the chemical industries in the 1800's that sulfur became a predominant component of the industrial revolution (Morse, 1985).

### SOURCES

Sulfur in all its forms is widely found. It combines directly with other elements except inert gases and nitrogen. It exists in its elemental state, as sulfides, sulfates or other organic compounds in rock as well as fossil fuels. Original supplies of sulfur were discovered around volcanic regions which may have been formed by sublimation, decomposition of hydrogen sulfide (H<sub>2</sub>S), metallic sulfides or biological action. Large deposits of elemental sulfur are mined on the gulf coast regions of the U.S. and Mexico, Poland, U.S.S.R. and Iraq. Metal sulfide ores are another source mined and smelted to recover the metals (iron, copper, lead, zinc, molybdenum, nickel, mercury, arsenic, antimony, and silver) and sulfur as sulfuric acid. Sulfates (gypsum- CaSO<sub>4</sub>\*2H<sub>2</sub>O) constitute a large fraction of the world's sulfur, but the economics to commercially segregate the element remain prohibitively high. Natural (sour) gas (and to a lesser extent geothermal steam/brine) represent a large reserve of sulfur. Substantial natural gas deposits occur in western Canada, the Near East, U.S.S.R., U.S., Mexico, France, Germany and Venezuela. Petroleum and Tar sands contain complex organosulfur compounds found in a wide range of forms and concentrations. Vast oil reserves high in sulfur content provide an additional source. Given adequate environmental controls, recovery systems can be developed and instituted. Coal and oil shale also offer potential for added output in the U.S. and elsewhere. Table I contains a glossary of definitions, grades and specifications for the sulfur industry.

<sup>1</sup> Earliest development is estimated around 500 B.C., Platou, 1981, p. 78

**Table I. Definitions, Grades, Specifications<sup>A</sup> for the Sulfur Industry.**

- Native sulfur.*— Sulfur occurring in nature in the elemental form.
- Pyrites.*— Iron sulfide minerals that include pyrites, marcasite, and pyrrhotite.
- Sulfur ore.*— Unprocessed ore containing native sulfur.
- Elemental sulfur.*— Processed sulfur in the elemental form produced from native sulfur or combined sulfur sources, generally with a minimum sulfur content of 99.5%.
- Frasch sulfur.*— Elemental sulfur produced from native sulfur sources by the Frasch mining process.
- Recovered sulfur.*— Elemental sulfur produced from combined sulfur sources by whatever methods.
- Crude sulfur.*— Commercial nomenclature for elemental sulfur.
- Brimstone.*— Synonymous with crude sulfur.
- Broken sulfur.*— Solid crude sulfur crushed to minus 8-inch size.
- Slated sulfur.*— Solid crude sulfur in the form of slate-like lumps produced by allowing molten sulfur to solidify on a water-cooled, moving belt.
- Prilled sulfur.*— Solid crude sulfur in the form of pellets produced by cooling molten sulfur with air or water.
- Bright sulfur.*— Crude sulfur free of discoloring impurities and bright yellow in color.
- Dark sulfur.*— Crude sulfur discolored by minor quantities of hydrocarbons ranging up to 0.3% carbon content.
- Sulfuric acid.*— Sulfuric acid of commerce produced from all sources of sulfur, generally reported in terms of 100% H<sub>2</sub>SO<sub>4</sub> with a 32.69% sulfur content.

<sup>A</sup> Morse, D. A., 1985, Sulfur, A Chapter from Mineral Facts and Problems, Preprint from Bulletin 675, U.S. Dept. of Interior, Washington, D.C., p. 2.

## PRODUCTION AND USES

Native sulfur found in the caprocks of salt domes and in sedimentary deposits is mined by the Frasch process. This process employs hot water which melts the elemental sulfur underground and uses compressed air to lift the liquified material to the surface. In 1986 Frasch sulfur accounted for 36% of domestic production compared with 30% domestic production in 1987. Approximately 87% of Frasch sulfur is used for domestic consumption with 13% exported. Recovered sulfur from petroleum refining, natural gas processing, coking plants, etc. accounted for 52% of the domestic output in 1986 and 59% of the output in 1987 (Morse, 1987). Also in 1987, U.S. exports of elemental sulfur (Frasch and recovered) exceeded 1.2 million metric tons (\$139.4 million) while imports topped 1.6 million metric tons (\$152.1 million). Canada, Mexico, and Venezuela provided over 99.9% of the total U.S. elemental sulfur imports for 1987 primarily high grade Frasch.

The Claus sulfur recovery process is used in conjunction with fossil fuel refinement and production. The process uses a hydrogen gas stream to saturate the refinery tail gas (H<sub>2</sub>S) which is burned in a controlled environment.

The sulfur dioxide produced is reacted with additional incoming H<sub>2</sub>S in a ratio of 1:2. The result is a high purity sulfur which is condensed and removed as a liquid. Residual H<sub>2</sub>S gas is further processed in tail gas treating units with little or no release of pollution to the air. The commercial (crude) sulfur is marketed in either solid or liquid form. In the U.S., sulfur is usually sold as liquid. In world markets, sulfur is shipped as a solid as either slabs (sheets) or prills (beads).

Sulfur's use as a major process chemical usually requires it to be converted to an intermediate prior to its use by industry. In many cases, the final products contain relatively little sulfur. Sulfuric acid is the most important of these intermediate products. About four-fifths of the sulfur consumption in the world is converted to sulfuric acid or produced directly in this form. U.S. exports of sulfuric acid (100% H<sub>2</sub>SO<sub>4</sub>) totaled 67 thousand metric tons (\$4.6 million) in 1986 and 98 thousand metric tons (\$5.8 million) in 1987. U.S. imports of sulfuric acid totaled 760 thousand metric tons (\$30 million) in 1986 and 766 thousand metric tons (\$24.8 million) in 1987. Sulfuric acid has many desirable properties and is most widely used as a mineral acid due to its low cost, relative ease of handling, storage, and reuse. Agriculture accounts for about 70% of domestic sulfur demand which can be related to phosphate fertilizer production. Sulfur is gaining importance as a soil conditioner because high grade phosphate fertilizers tend to be deficient in the sulfur content necessary for plant protein synthesis. Other uses of sulfur include vulcanization of rubber, cements and electric insulators, some ointments and medicinals, gunpowder and matches (New Encyclopedia, 1974-75). Sulfur is also employed in the manufacture of soaps, leather, plastics, refrigerants, bleaching agents, drugs, dyes, paints and paper (Encyclopedia of Science). The Attachment shows sulfur-sulfuric acid supply and end-use relationships<sup>1</sup>.

## GEYSERS POWER CYCLES

The Geysers geothermal field in northern California yields relatively dry, superheated steam which in turn is used to produce electricity. The steam is extracted from wells drilled at depths ranging from 5,000 to 10,000 feet. Small particulate are centrifugally separated from the steam (cyclone separation) which is then directed into a turbine-generator system where mechanical torque produces an electrical voltage which in turn is transmitted to users. The "spent" steam is funnelled into a condensing system. Significant quantities of dissolved gases (including H<sub>2</sub>S, ammonia, and carbon dioxide) are entrained in the steam

<sup>1</sup> Based on 1983 data, Morse, 1985.

matrix. As a result, the gases (primarily H<sub>2</sub>S) must be removed and abated to maintain the power cycle vacuum and to mitigate environmental impacts. There are two main condensing systems: direct contact and surface contact<sup>1</sup>.

Direct contact condensers mix cooling water directly with the spent steam. Caustic solution is added to the cooling water to solubilize H<sub>2</sub>S into the water phase. Surface contact condensers use a tube and shell method whereby cooling water is passed through bundles of long metal tubes with large surface areas for heat transfer. The spent steam contacts the tubes, condenses to liquid and is collected in the bottom of the condenser. The majority of the gases are evacuated from the condenser by steam/gas ejectors which direct the H<sub>2</sub>S-laden gas to a tail gas treatment unit. In some instances, the steam condensate contains enough ammonia (basic) to cause H<sub>2</sub>S to solubilize similar to the direct contact system. The relative degree of separation is called "partitioning." The better the partitioning, the more efficient the H<sub>2</sub>S removal. In situations where the partitioning is poor, abatement chemicals must be added. Figure I shows a generic power cycle flow diagram for surface contact systems.

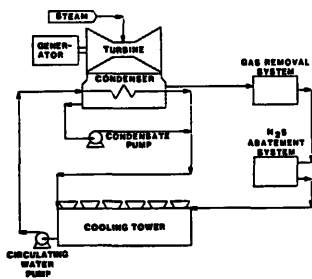


Figure I. Generic power cycle flow diagram.

### GEYSERS SULFUR

H<sub>2</sub>S abatement chemicals must be added to direct contact systems, and in the case of poor partitioning, to surface contact systems. Iron chelate derivatives (HEDTA) in the presence of dissolved oxygen oxidize the solubilized HS<sup>-</sup> to elemental sulfur. The elemental sulfur is typically contaminated with hydroxylated metal sulfides (iron, arsenic, mercury, zinc, etc.) that form a sludge-like material which settles to the bottom of cooling water basins and must be disposed of as a waste<sup>2</sup>.

- <sup>1</sup> Direct contact systems were the first condensing systems to be used at the Geysers.
- <sup>2</sup> This material can affect heat transfer properties and is removed during outages and overhauls.

When partitioning is favorable, 99.99% of the evacuated H<sub>2</sub>S mass flow is converted to elemental sulfur by an aqueous oxidation-reduction system known as "Stretford." This system uses vanadium-based chemistry in the presence of sufficient alkalinity, anthraquinone disulfonic acid (ADA) and dissolved oxygen which catalytically oxidizes HS<sup>-</sup> to elemental sulfur and regenerates the active oxidation species of vanadium (+5). The system is agitated and aerated so the sulfur particles float to the surface where they are collected, washed and melted to a liquid state. This "molten" product is marketed and sold to the chemical industry as feedstock for sulfur derivatives. In some instances, sulfur production exceeds the system's capacity to melt. In this case, a side stream of sulfur solids must be removed and melted elsewhere or be disposed of as a waste stream.

### ENVIRONMENTAL REGULATION

In 1976, the U.S. Congress passed the Resource Conservation Recovery Act (RCRA). The Act required generators of hazardous waste to handle, store, transport and dispose of this material in a manner which minimizes hazards to human health and the environment (RCRA, 1976). RCRA also made it incumbent upon the generator of any waste stream to evaluate the potential hazardous properties and track the material from "cradle-to-grave". Four generic hazardous waste categories were identified: ignitability, corrosivity, reactivity, and toxicity. If a given waste stream's properties fall into any or all of the categories, the waste is considered hazardous and normally is captured under RCRA jurisdiction. Geothermal sulfur has been granted an exemption from the RCRA provisions and therefore does not come under its purview. In 1977 environmental legislation enacted in California adopted similar criteria to RCRA called the Hazardous Waste Control Act (HWCA) which in many respects is more stringent (HWCA, 1977). The legislation set forth analogous provisions that would also protect public health and the environment. The California law also included testing, identification and characterization of waste properties. While geothermal sulfur is RCRA exempt, it is not generally exempted under HWCA. As a consequence, Geysers waste sulfur solids were evaluated for hazardous properties.

### HAZARDOUS WASTE EVALUATION

Pacific Gas and Electric Company, Geysers Power Plants began a testing program to identify and quantify hazardous constituents of their sulfur. The study primarily focused on post-washed sulfur solids upstream of melting. Analyses of this material indicated that of the four major hazard categories (as in RCRA), only specific toxicity limits were consistently

<sup>1</sup> From point of generation to final disposal.

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exceeded. There are several subcategories within toxicity: Aquatic Bioassay, Soluble Threshold Limit Concentration (STLC) and Total Threshold Limit Concentration (TTLC) for organics and inorganics. STLC and TTLC methods are described in the California Assessment manual, Waste Extraction Test (CAM WET). Table II shows the CAM WET STLC and TTLC limits for inorganic analytes.

Table II. Shows Soluble/Total Threshold Limit Concentrations<sup>A,B</sup> - Inorganic Analytes.

Analyte	STLC (mg/L)	TTLC (mg/kg)
Antimony	15	500
Arsenic	5	500
Barium	100	10,000
Beryllium	0.75	75
Cadmium	1.0	100
Chromium	560	2,500
Chromium (+6)	5	
Chromium (+3)	560	
Cobalt	80	8,000
Copper	25	2,500
Lead	5	1,000
Mercury	0.2	20
Molybdenum	350	3,500
Nickel	20	2,000
Selenium	1.0	100
Silver	5	500
Thallium	7	700
Vanadium	24	2,400
Zinc	250	5,000

<sup>A</sup> Soluble Threshold Limit Concentration (STLC), California Code of Regulations, Title 22, Article 11, Sections 66194, 66699 et seq.  
<sup>B</sup> Ibid, (TTLC), Sections 66206, 66696 et seq.

Aquatic Bioassay tests quantify the mortality rate of a given test species (flat head minnows, steelhead trout fingerlings<sup>1</sup>) in various concentrations for a specific waste stream. From this rate, wastes are interpreted as having some relative degree of toxicity. Typically, 0% mortality rates at concentrations greater than 750 mg/l are considered non-toxic<sup>2</sup>.

STLC's are determined using a 48-hour extraction procedure with a (citrate) buffer at pH 5. This test was intended to quantify leachability characteristics that could be used to model groundwater contamination scenarios and identify potentially responsible parties (PRPs) for remediation purposes. TTLCs are used to determine maximum contaminant levels and

<sup>1</sup> Native, biologically sensitive species are typically used.  
<sup>2</sup> Some degree of mortality at elevated concentrations can be construed as relatively non-toxic.

tests employ rigorous acid digests. Limits for TTLCs are based on respirable toxicity (cancer) risks which pose threats to public health.

Geysers geothermal sulfur has sometimes been found to contain amounts of TTLC mercury above the regulatory limits. This triggers a hazardous waste designation for washed geothermal sulfur solids. This classification has resulted in the land disposal of this material into an approved and certified Class I Hazardous Waste Disposal Facility (Classification and Siting Criteria). Table III lists a typical STLC/TTLC inorganic analysis.

Table III. Shows typical Geothermal sulfur STLC/TTLC Analysis<sup>A</sup> - PG&E/Geysers Unit 18<sup>B</sup>

Analyte	STLC (mg/L)	TTLC (mg/kg)
Antimony	<1	<100
Arsenic	0.7	<10
Barium	<1	<100
Beryllium	<0.01	<1
Cadmium	<0.1	<10
Chromium	0.1	<10
Chromium (+6)	<0.1	n/a
Chromium (+3)	<0.1	n/a
Cobalt	<1	<100
Copper	<0.1	<10
Lead	<0.1	<10
Mercury	<0.2	26
Molybdenum	<1	<100
Nickel	<0.1	<10
Selenium	<0.1	<10
Silver	<0.1	<10
Thallium	<1	<100
Vanadium	15	150
Zinc	0.4	10

<sup>A</sup> Reproduced from original analysis with permission from Pacific Gas and Electric Company (PG&E), San Francisco, California, 1989.  
<sup>B</sup> PG&E/Geysers currently has six geothermal power plants in operation which use the Stretford H<sub>2</sub>S Abatement process for production of molten sulfur.

WASTE MINIMIZATION

The evolution of environmental regulation started off on a slow, tortuous path. Society had to rectify the prior years of pollution incurred as a result of technological ignorance and the rapid expansion of the industrial revolution. Legislation such as RCRA, the Clean Air and Water Acts were adopted as a reaction to the blatant degradation and contamination of U.S. land, air and water. As a result, some progress has already been made in detoxifying a significant number of "wastelands", groundwater and air. The U.S. Congress and other leaders recognize the ecological interrelationships of national/global industrial development and appear to be committed to taking a more proactive approach. The philosophy in California has taken the form of a preferred hierarchy of waste minimization:

source reduction, recycling, treatment, and disposal. The fundamental basis is simple: prevent wastes from being generated at the source. Source reduction implies substitution of hazardous starting materials for nonhazardous ones while optimizing process efficiencies. Recycling means reuse of waste byproducts by either returning them back to the original process or by finding another environmentally acceptable end use for them. Treatment means chemically, physically or biologically changing a waste stream to render its hazardous components nonhazardous<sup>1</sup>. Residual disposal is the last option that should only be employed when the preceding alternatives have been exhausted.

The molten sulfur currently produced from the Stretford H<sub>2</sub>S abatement system is sold to sulfuric acid producers as well as used for feedstock for lime sulfur (CaSO<sub>4</sub> and its hydrated forms). The limiting criteria for this material has been the ash content. The ash content of the material is related to the dissolved salt concentrations in the Stretford solution (sodium salt species of thiosulfate, sulfate, degraded vanadate, and organic acid). The market value of this material fluctuates based on production output, inventories and availability. If a glut exists, the molten material may be discounted in relation to its ash content. Molten sulfur is sold as a material and is not considered to be a waste. The washed sulfur solids from both the surface and direct contact systems are considered to be waste streams.

In the case of Stretford sulfur solids, source reduction involves increasing sulfur melting capacity and reliability. These types of modifications are currently being pursued but have lengthy design and installation lead times. Melting sulfur solids can also result in pipe/pump plugging and the associated mechanical maintenance can be costly and time consuming<sup>2</sup>.

Sulfur solids from direct contact systems can be reduced by combusting the H<sub>2</sub>S gas to SO<sub>2</sub> which is scrubbed by caustic solution into the cooling water loop and eventually returned (reinjecting) to the ground. H<sub>2</sub>S partitioning in the condenser remains a factor and extra abatement chemicals must be added. The formation of sulfur solids still occurs but at a slower rate. Solids from direct contact systems are not combined with Stretford solids for melting.

**MARKETING STRATEGIES**

In a supply-demand economy it makes prudent business sense to stimulate buyer interest and

<sup>1</sup> Incorporating volume reduction practices.  
<sup>2</sup> These factors directly affect operating economics.

competition. To do this effectively, the producer must be aware of the particular market's strengths and weaknesses. A major oil refinery can produce in excess of 2,000,000 metric tons of Claus sulfur<sup>1</sup> per year compared with approximately 20,000 metric tons of sulfur from PG&E geothermal sources. The comparison serves to illustrate the production range from one producer to the next. Geysers sulfur, although limited in quantity and quality, does have some marketing advantages:

**Location -**

California industry has almost every major oil and chemical producer doing business in the state. The west coast also has many export locations where sulfur products can be shipped to clients abroad. Transportation can become prohibitively expensive when feedstock is brought from out of state. A central supply location with confirmed and consistent output schedules can help industry hedge vacillating market conditions<sup>2</sup>.

**Inexpensive Feedstock -**

Geothermal waste sulfur solids as stated above are currently land-filled in a facility capable of taking the most hazardous waste. The cost to dispose of a ton of material can range from \$190-233 (Table IV). Passage of the 1984 RCRA (Hazardous and Solid Waste) Amendments and California Senate Bill (SB) 1500 prohibits the land disposal of all untreated wastes by May 8, 1990. These laws eliminate or restrict many current disposal options. The laws serve to motivate industrial sectors to review their processes and reduce and recycle wastes wherever possible. An extension of this principle is to receive recycled material for feedstock at reduced or no cost, or even better, positive cash flow!

Table IV. Shows Geothermal waste sulfur solids - Disposal Costs<sup>A</sup>.

Activity	\$ Cost/Ton
Land Disposal	105.00
Transportation <sup>B</sup>	57.00
California State Board of Equalization	16.10
Annual Superfund Tax	9.65
Annual Hazardous Waste Generator Fee <sup>C</sup>	2.40
Subtotal	190.15
<u>Additional Fees</u>	
Excessive Weight <sup>D</sup>	20.00
Stabilization <sup>E</sup>	22.00
<b>TOTAL</b>	<b>233.15</b>

<sup>A</sup> 1988-1989 estimates include local taxes, user fees, etc.  
<sup>B</sup> End dump truck transfer, f.o.b. Kettleman Hills, CA  
<sup>C</sup> \$48,000 per year for PG&E/Geysers, 20,000 tons generated.  
<sup>D</sup> Greater than 1,800 lbs./yd<sup>3</sup>.  
<sup>E</sup> When free liquids are present.

<sup>1</sup> Bright yellow, high purity.  
<sup>2</sup> Pricing and production can vary significantly, Morse, 1985, p. 1-15.

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Industry is beginning to accept the idea of using retrograde (waste) material in exchange for accepting contractual responsibility for cradle-to-grave liability from their production waste streams (slag, bottom ash, etc.). The capitalization economics become favorable when producers consider free starting material and possibly payment in exchange for potential long term liability considerations.

**Handling/Transportation -**

Waste sulfur solids are de-watered in two centralized places, one for Stretford, and one for Cooling Water. The filtrates are recycled back to the original process type and reused. The solids are conveyed or physically relocated into bins. The solids generally contain 40-60 wt% moisture and are handled with minimum dusting. The waste streams are never kept on site longer than 90 days prior to disposal. To minimize the costs, sulfur solids are also bulk loaded into end dump trucks and transported by certified hazardous waste haulers.

**Future Opportunities -**

The pricing for elemental sulfur varies with production sources and transportation costs (Table V). As more countries adopt air pollution controls; hydrocarbon and non-ferrous metals producers refine regional outputs; and relative cost advantages offered by transport modes fluctuate; sulfur output will increase and the sources will become more diversified (Fike, 1972). It is projected that the world sulfur demand will show an average annual growth rate of 3.4% (Table VI) through the year 2000 which will be offset by increases in domestic sulfur production.

**Table V. Reported sales values - shipments of sulfur - f.o.b. mine or plant<sup>A</sup>.**

Year	(Dollars per metric ton)		
	Frasch	Recovered	Average
1983	100.76	76.22	87.24
1984	109.20	80.02	94.31
1985	122.62	92.11	106.46
1986	123.79	92.06	105.22
1987	107.15	79.63	89.78

<sup>A</sup> Morse, D.A.; Sulfur, Preprint from the 1987 Mine and Minerals Yearbook; U.S. Department of Interior; Washington, D.C., p 13.

**Table VI. Summary of Forecasts of U.S. and Rest-of-World sulfur demand - 1990 and 2000<sup>A</sup>.**

1983	(Thousand metric tons)				Probable Average Annual Growth Rate 1983-2000 (percent)	
	2000 Forecast Range		Probable			
	Low	High	1990	2000		
<b>United States:</b>						
Total.....	10,988	15,500	25,000	13,800	18,800	3.2
Cumulative....	---	225,000	297,000	87,800	251,000	---
<b>Rest of World:</b>						
Total.....	42,500	70,000	100,000	54,000	75,000	3.5
Cumulative....	---	950,000	1,171,000	342,200	998,000	---
<b>World:</b>						
Total <sup>B</sup> .....	53,500	85,000	125,000	67,600	95,000	3.4
Cumulative....	---	1,175,000	1,468,000	430,000	1,250,000	---

<sup>A</sup> Morse, C.A.; Sulfur, A Chapter from Mineral Facts and Problems; Preprint from Bulletin 675, U.S. Dept. of Interior; Washington, D.C., 1985; p 13.

<sup>B</sup> Data may not add to totals shown because of independent rounding.

The number of markets for geothermal sulfur appear to be increasing. The land ban for untreated wastes is creating the need for additional recycling options. These options include construction and paving materials; and chemical production feedstocks.

**Construction -**

Sulfur concrete and mortar uses have been studied extensively (McBee, 1981; Platou, 1981). Concretes prepared with sulfur as a binder have mechanical properties comparable to portland cement concretes. Sulfur concrete can be formulated to be acid and salt resistant for use in electrolytic cells, industrial flooring, and pipe. Sulfur mortar applied at 120-150°C containing 90-95 wt% sulfur and small percentages of fiber and additives has been used to coat and join stacks of bricks, blocks and similar materials. The material solidifies immediately to form a hard impervious surface.

**Paving Materials -**

During the past century, many papers have been written describing the preparation of sulfur-asphalt materials (Lee, 1971; Sullivan, 1981). In 1971 a comprehensive report was published describing major types of sulfur-paving materials: sulfur extended asphalt (SEA), sand-asphalt-sulfur (SAS), and recycled asphalt materials. SEA is formulated by replacing some asphalt in conventional binders with 30-50 wt% sulfur. SEA has been shown to be more resistant to rutting and deformation during hot weather and is very resistant to gasoline, diesel and other solvents. During 1981 small scale road trials were organized in seven states and the durability and longevity are currently being evaluated. SAS has been utilized as a way of improving coarsely graded aggregates with

essentially no reduction in asphalt content. Existing roads fail because asphalt wears away and becomes brittle. The feasibility of using sulfur to soften or reduce the viscosity of oxidized binder in recycled pavements was successfully demonstrated by the Bureau of Mines and others (McBee, 1978).

#### Chemical Feedstocks -

One chemical producer in northern California has already tested geothermal sulfur suitability as sulfuric acid feedstock and has entered into preliminary "trial burn" contracts to characterize the pros and cons associated with the material. Major concerns appear to be the cost to capitalize for purification equipment, obtaining regulatory permits, and waste residues and effluents. Chemical producers appear to be willing to accept liability for this material for the appropriate price and guaranteed supplies.

#### CONCLUSION

Sulfur is one of the most abundant native elements found on earth. It is mined directly from the ground or recovered by various processes (Claus, Stretford). Sulfur is often used as a chemical intermediate ( $H_2SO_4$ ) for scores of products which include fertilizers, paints and paper. The Geysers geothermal resource produces electricity and elemental sulfur (molten). Byproducts include sulfur solids of two general types: Stretford and Cooling Water. Both types of waste streams have their own specific hazardous properties and application for commercial use. Federal and state environmental regulations (RCRA, HWCA) require the safe and legal handling, storage, treatment, and transport of wastes. Geothermal sulfur is RCRA exempt but subject to California waste regulations. The regulated hazardous waste category pertaining to Geysers sulfur is toxicity (STLC/TTLIC arsenic, mercury). Waste minimization employs source reduction, recycling, treatment and finally disposal. Marketing strengths for geothermal sulfur include: a central California location for use and transport to other market sectors; an inexpensive feedstock; and ease of handling, storing, loading and transporting the material to receiving destinations. Future markets for geothermal sulfur include construction and paving materials as well as diversified applications within the chemical industry. Geothermal sulfur output is consistent and ongoing for as long as the resource is active. This suggests an optimistic future for geothermal sulfur in the years to follow.

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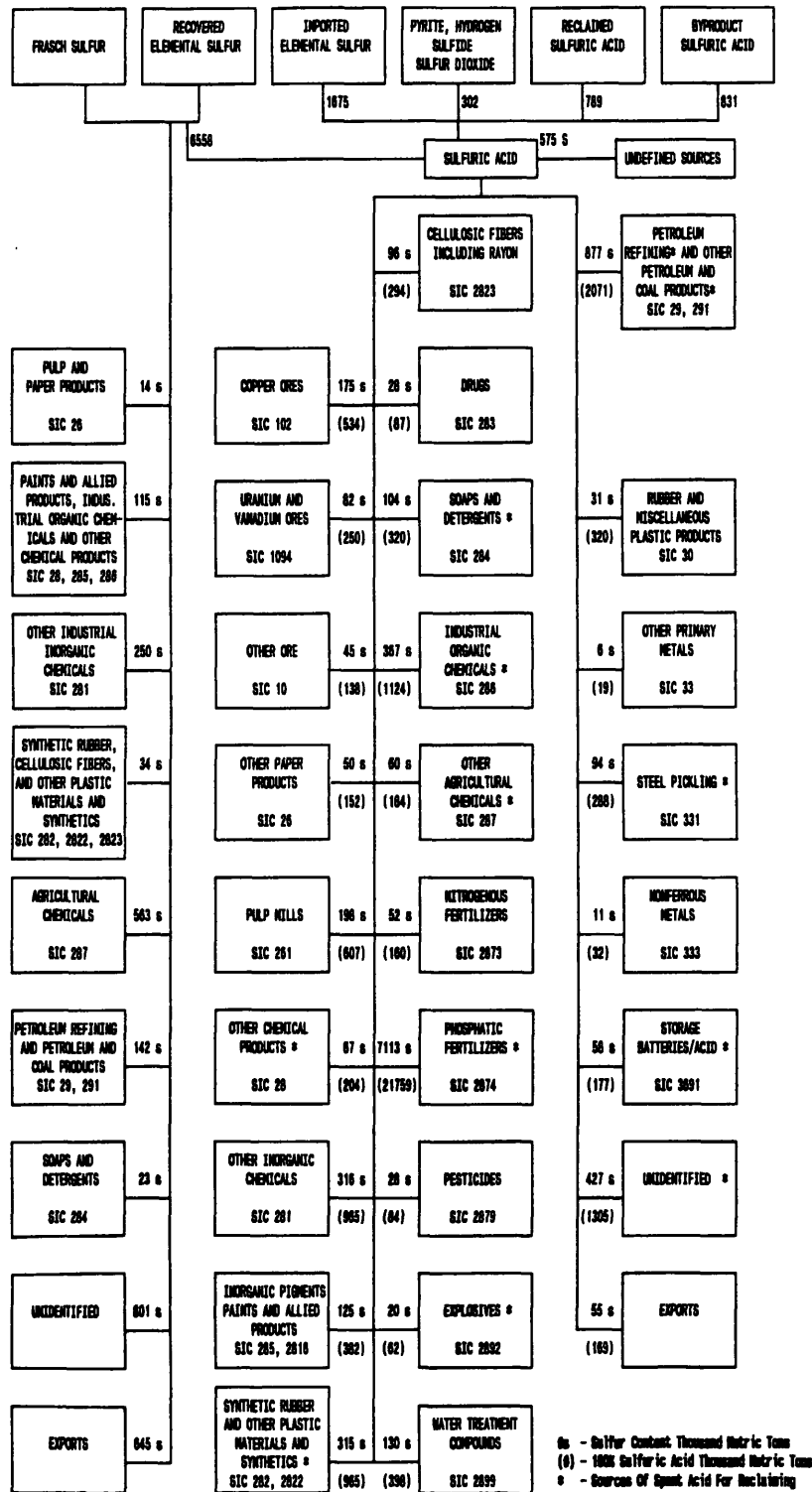


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ATTACHMENT

Sulfur-Sulfuric Acid Supply and End-Use Relationships - 1983\*



s - Sulfur Content Thousand Metric Tons  
 (s) - 100% Sulfuric Acid Thousand Metric Tons  
 \* - Sources Of Sulfur Acid For Reclaiming

\* Morse, D.A., 1985, p.8