

SILICA

By Wallace P. Bolen

Beginning with this report, the U.S. Geological Survey (USGS) will report industrial sand and gravel, tripoli, specialty silica stone, and quartz crystal in a report entitled "Silica." There are several reasons why this is being done. All of these commodities are essentially crystalline silicon dioxide (SiO_2) with variations mostly related to their crystal sizes and minor or trace impurities. Additionally, tripoli usage has increasingly been shifting from fine abrasive to filler and often competes with ground sand. (Tripoli had previously been covered by the USGS abrasive minerals specialist.) In this report, the four categories noted above will be reviewed in separate sections. Future reports will likely continue the refinement of the silica chapter in order to provide the most useful and meaningful data.

The sections on tripoli and special silica stone covers tripoli and other fine-grained, porous silica materials that have similar properties and end uses (e.g., rottenstone and novaculite). It does not include certain fine-grained or porous silica materials, such as pumice, covered in the Minerals Yearbook published by the USGS.

Industrial Sand and Gravel

Industrial sand and gravel production, exports, and imports decreased in 1996 compared with 1995. However, because of the decreased exports, the apparent consumption of about 26.4 million metric tons was essentially unchanged from 1995. Industrial sand and gravel, often termed "silica," "silica sand," and "quartz sand," includes high SiO_2 content sands and gravels. These sands are used in glassmaking, for foundry, abrasive, and hydraulic fracturing applications, and many other uses. The specifications for each use varies but silica resources for most markets are abundant. The leading producing States were Illinois, Michigan, California, New Jersey, and Wisconsin. In almost all cases, silica mining employs open pit mining methods with standard mining equipment. Sand and gravel mining, in the vast majority of cases, has little environmental impact except for temporarily disturbing the immediate environment while mining operations are active.

Production of industrial sand and gravel in 1996 decreased to 27.8 million metric tons, about 1.5% less than 1995's production. This decrease, although minor, represents the first year to year decrease in production since 1991. Production decreased in response to lower demand for many uses including: blast, container and specialty glass, filtration, foundry, recreational, traction sands and for silica used in the "whole grain filler/building products" category.

Exports of industrial sand and gravel dropped nearly 24% compared with 1995. However, the value of the exports

increased about 7%, to \$113 million. Also dropping, imports of industrial sand and gravel in 1996 were only 12% of the amount imported in 1995. The annual amount of imports has been consistently quite small but is composed mostly of many small shipments of high-value silicas. Domestic apparent consumption of industrial sand and gravel in 1996 was 26.4 million tons, unchanged from 1995. (*See table 1.*)

Legislation and Government Programs.—The regulation of respirable silica continued to concern miners and consumers of many minerals that contain crystalline silica, especially the industrial sand and gravel industry. The Occupational Safety and Health Administration (OSHA) listed crystalline silica as one of their top five priorities for formal rulemaking (Chemical and Engineering News, 1996d). Other regulatory government agencies, including the Mine Safety and Health Administration, and the Environmental Protection Agency continued to study, or planned to further study, silica related health concerns.

In 1996, OSHA began a national special emphasis program on crystalline silica, including extensive outreach and inspections, in order to reduce the potential threat of silicosis. To encourage voluntary protection measures, OSHA would conduct an outreach program for 60 days before proceeding with enforcement under existing OSHA standards (Ceramic Industry, 1996c).

Fiberglass, a product which is produced from silica, has also been scrutinized by some Government and private organizations. Public health concerns about fiberglass were addressed in a report released by the Natural Resources Defense Council, a New York City-based environmental research group. The group cited a study by the International Agency for Research on Cancer that claims fiberglass is a potential carcinogen (Engineering News Record, 1996b).

Production.—Domestic production data for industrial sand and gravel were developed by the USGS from a voluntary survey of U.S. producers. The USGS canvassed 82 producers of industrial sand and gravel with 146 active operations. Of the 156 industrial sand and gravel operations surveyed, 119 (76%) reported to the USGS. Their combined production represented about 88% of the U.S. total published in table 1. The production of nonrespondents was estimated based on previously reported information and other factors. Of the 156 operations, 146 (94%) were active and 10 idle.

The Midwest (East and West North Central divisions) continued to lead the Nation with about 42% of the 27.8 million metric tons produced in the United States, followed by the South (South Atlantic, East and West South Central divisions) with about 35% and the West (Pacific and Mountain divisions) with 14%. (*See table 2 and figure 1.*)

The five leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, Michigan, California, New Jersey, and Wisconsin. Their combined production represented 44% of the national total. Notable production changes occurred in Michigan which had a 8.8% decrease in production and New Jersey which experienced a 4.5% decrease, compared with 1995. Production in California, Illinois, and Wisconsin was virtually unchanged from 1995 to 1996. In 1996, nine States had increased production, 14 States had decreased production, and 14 States stayed about even compared with 1995. Alabama, Idaho, and Louisiana reported the largest increases while Georgia, Tennessee, Texas, and Virginia reported the largest decreases. (See table 3.)

About 77% of the industrial sand and gravel was produced by 49 operations, each with an annual production of more than 200,000 tons. The 10 leading producers of industrial sand and gravel were, in descending order of tonnage, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., Oglebay Norton Industrial Sands Co., Badger Mining Corp., Nugent Sand Co. Inc., Simplot Industries Inc., Construction Aggregates Corp., W.R. Bonsal Co., and Short Mountain Silica Co. Their combined production, from 58 operations, represented 71% of the U.S. total. (See tables 4 and 5.)

Merger and acquisition activity continued in 1996 as Unimin Corp., of New Canaan, CT, solidified its number one position with the purchase of the Morie Company from South Jersey Industries. Morie, consistently ranked in the top 10 during the last decade, operated industrial and construction sand and gravel operations in Alabama, Georgia, New Jersey, and Tennessee.

Whibco Inc., of Leesburg, NJ, a top 20 producer, reported better than expected sales in 1996 and announced the reopening of their Wareham, Massachusetts plant, after a costly upgrade of the plant's facilities. The upgrades allow the company to comply with State and Federal environmental statutes and provide expanded services to their customers. The New England region has a small number of silica producers due to unfavorable geology and local land use patterns. Whibco also opened its new corporate office at 87 East Commerce Street in Bridgeton, NJ. (Strelczyk, 1997)

Granite Rock Co., of Watsonville, CA, took over the operations of Santa Cruz Aggregates Co. on January 1, 1996. Granite Rock, which had leased the property to Santa Cruz, decided not to renew the lease and assumed operations at that location. Beside continuing to service the glass and recreational sand needs of Santa Cruz Aggregate's customers, Granite Rock plans to expand into other markets, particularly construction-related markets.

New producers included with this report are Custom Aggregates and Grinding of Houma, LA, and TEC Minerals Co., of Romayor, TX.

Colorado Lien Co., Fort Collins, CO, reported the closure of their LaPorte, CO, mine and plant in February. The plant operated for 30 days in 1996 and produced sand for the container glass market.

Consumption.—Sand and gravel production reported by producers to the USGS was actually material used by the

companies or sold to their customers. Stockpiled material was not reported until consumed or sold. Of the 27.8 million metric tons of industrial sand and gravel sold or used, 37% was consumed as glassmaking sand and 23% as foundry sand. Other important uses were frac sand (6%) and abrasive sand (5%). (See table 6.)

The production of industrial sand and gravel in the United States has developed in response to market location and vice versa as industry sometimes located near silica resources. Because silica deposits (or resources) are found throughout the United States, locating a consuming industry specifically to be near a silica source was not always a priority, although certainly a consideration. The auto industry was originally located in the Midwest near iron, coal, clay, and silica resources. Therefore, foundry sands were greatly exploited in Michigan, Ohio, Indiana, Illinois, and other regional States. This resulted in over 78% of the foundry sand being produced in the Midwestern region in 1996.

The glass industry, somewhat conversely, had to locate plants where they could minimize the shipping distance of finished glass products. Hence, glass plants were more evenly distributed as 39% of glass sand was produced in the Southern region, 33% in the Midwest, 16% in the West, and 12% in the Northeast, in 1996. To varying degrees, all silica production was similarly influenced as markets and consuming industries either forced the silica mining location or were forced to locate near the silica source.

The share of silica sold for all types of glassmaking as a percentage of all silica sold was 37%. This is slightly less than in 1995 but still higher than in 1985 when glass markets consumed only 35% of silica sold.

The amount of sand sold for glass container production continued to decrease, falling nearly 9% from 1995 levels, while glass container shipments dropped 5.4% during the year (Ceramic Industry, 1997). Wide mouth container shipments were down 10% while narrow neck container shipments were only down around 3%. Sales of glass containers are negatively influenced by competition from plastics, metals, and other packaging materials. Glass sand sales are also negatively influenced by this competition and by the recycling of glass containers. Also contributing to the decrease in domestic glass container sales, imported glass containers are now about 8% of domestic apparent consumption (Glass Industry, 1997).

Flat glass, unlike container glass, continued to be a good growth prospect for silica sales. Sales of sand for flat glass production increased nearly 5% even though shipments of flat glass decreased about 3% (Ceramic Industry, 1997). This probably took place because flat glass demand did not decrease until the end of 1996, after glass sand purchases were made. Flat glass demand remained relatively strong due to a healthy housing market and modest growth in the sales of light vehicles.

Silica is used in ceramics in both whole grain and ground form. Generally, the whole grain is used in the ceramic body, while the ground silica is used to decrease viscosity and expansion coefficient in ceramic glazes and other ceramic applications. Beyond traditional ceramics, advanced ceramics,

such as silicon nitride and silicon carbide, represent a growing market for silica and silica-based chemicals.

Silica is used in plastics as a filler, extender, and reinforcer. Specifically, it is used to thicken liquid systems, as a thixotropic agent, flattening agent, and is used to avoid plateout in polyvinyl chloride. As segregated for this survey, consumption of ground silica for filler was 192,000 tons and whole grain filler sales amounted to 1.23 million tons in 1996.

Specialty silicas are usually produced by means of chemical and thermal processing of natural silica, silicon metal, or as a byproduct of other mineral or chemical processing. Although the USGS did not specifically collect information for specialty silicas, their consumption does affect natural silica sales. Specialty silicas and silanes (silica chemicals), included, but were not limited to, colloidal silicas, fumed silica, fused silica and quartz, precipitated silica, silica gels, silicones, and ultra-high purity silica. These silicas are used in a variety of industries and products including abrasives, beverages, catalysts, coatings, electronics, encapsulants, food, health care, optics, paper and packaging, plastics, refractories, rubber, specialty coatings, textiles, water treatment, and many others. On table 6, industrial sand and gravel which would find its way into these specialty silicas is most likely reported in the categories "chemical" and "silicon metal." Silica sales for chemical production remained about equal to 1995's levels, at 650,000 tons. Reported sales of silica gravel for silicon and ferrosilicon production increased over 20% in 1996 compared with 1995. The main uses for silicon metal are in the manufacture of silanes, semiconductor grade silicon, and in the production of aluminum alloys.

Another use for silicates is the cleanup of soils contaminated with hazardous waste. PQ Corp., of Valley Forge, PA, a manufacturer of silicas and silicates, uses silicates with portland cement to solidify and stabilize soil at hazardous waste sites. The silicates act as physical and chemical binder, resist acid attack, and improve the overall economics of waste treatment (Chemical Marketing Reporter, 1996d).

Northeast.—Cumberland County, NJ, continued to be the largest source for the glass and foundry sand markets in the region. Unimin and U.S. Silica, which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Unimin and Ricci Brothers Sand Co. Inc., Cumberland County, produced a major percentage of the abrasive blast sand in the region. Whibco's operation in Cumberland County, was also a large producer of foundry sand in the region.

Midwest.—Unimin's plants in La Salle and Ogle Counties, IL; LeSueur and Scott Counties, MN; Jefferson County, MO; and Columbia County, WI, were among the leaders in producing sand for all four major markets: the blast, foundry, frac, and glass sand markets. Fairmount Minerals, with major operations in Berrien and Van Buren Counties, MI, Geauga County, OH, and La Salle County, IL, was also a major producer of sand for the four major markets in the region. U.S. Silica's plant in La Salle County, IL, was a large producer for the glass and foundry

markets and their St. Louis County, MO, operation was a large producer for the glass market. Construction Aggregates Corp., Ottawa County, MI; Nugent Sand Co. Inc., Muskegon County, MI; and Sargent Sand Co., Wexford County, MI; were all large producers for the foundry industry. Badger Mining, Jackson and Green Lake Counties, WI, was a major producer for the foundry and frac markets. Kaw Valley Sand and Gravel Co., Wyandotte County, KS, and All Purpose Sand Co., St. Louis County, MO, were major producers of blast sand. Oglebay Norton's plants in Knox and Perry Counties, OH, and Manley Brothers of Indiana, La Salle County, IL, were significant producers for the glass market.

South.—Unimin and U.S. Silica Co. were two of the largest producers of sand for the glass and foundry markets. Unimin's major plants were in Izard County, AR; Marion County, GA; Richmond County, NC; Pontotoc County, OK; Carroll County, TN; Johnson County, TX; and Frederick County, VA. U.S. Silica's Bullock County, AL; Johnston County, OK; Lexington County, SC; Limestone County, TX; and Morgan County, WV, operations were their major contributors for these markets. Cobb Industrial Corp., Red River Parish, LA; Custom Aggregates and Grinding, Inc., Terrebonne Parish, LA; Huey Stockstill Inc., Pearl River County, MS; Mid-State Sand and Gravel Co., Allen and East Baton Rouge Parishes, LA; and Specialty Sand Co., Newton County, TX, were large producers of blasting sand. W.R. Bonsal and Co. and B.V. Hedrick Gravel and Sand Co., Anson County, NC, and Martin Marietta Aggregates, Macon County, AL, produced a large percentage of the industrial gravel used in the production of silicon and ferrosilicon. Oglebay Norton, with two operations in McCulloch County, TX, was the largest producer of frac sand, and an important contributor of blast sand for the region. Whibco in Kershaw County, SC, was an important producer of foundry sand. APAC Arkansas Inc., Muskogee County, OK; and Short Mountain Silica Co., Hawkins County, TN, were important producers of glass sand.

West.—Owens-Illinois, Simplot Industries, Unimin, and Lane Mountain Silica were the largest producers of glass sand in the region, with major operations in Amador County, CA; Clark County, NV; Contra Costa County, CA; and Stevens County, WA, respectively. Lane Mountain Silica; Lone Star Industries Inc., Monterey County, CA; and P.W. Gillibrand Co., Ventura County, CA; were the major suppliers for the sand blasting industry in the region. Simplot Industries also supplied a large portion of the foundry sand consumed. FMC Corp., Power County, ID; Rhône-Poulenc Basic Chemicals Co., Beaverhead County, ID; and Monsanto Industrial Chemicals Co., Caribou County, ID, each produced industrial gravel for use as a flux in elemental phosphorus production. The Ashton Co., Pinal County, AZ, was the largest producer of silica for metallurgical flux in the region.

Recycling.—Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and airblasting sands, and, increasingly, post consumer glass and scrap glass (cullet) that substitutes for batch mix (including

industrial sand). Most glass recycling was restricted to container glass, with green and amber cullet consumed in greater amounts for glass production because it is more difficult to use cullet in flint batch mixes.

Glass container recycling was estimated at 38% of consumption in the United States for 1996. This included glass used in glascrete (cullet used in portland and asphalt concrete) and those that were refilled, and represents an increase from the 1995 rate of 37% (Glass Packaging Institute, 1997). The price for cullet varied based on region and grade (flint (clear), brown (amber), or green) and location. Cullet from consumers generally passes through a processor, who receives it from municipalities, counties, etc., and the processor then provides it to the glassmaker.

As the level of cullet used in glass production increases, so does the level of quality required. Contamination of cullet by ceramics and nonmagnetic materials is an increasing concern. Because of the increased use of recycled glasses, restrictions on the iron and chromium levels in glass sands have become stricter and the proportion of refractory particles allowed has been reduced to almost zero. The Fe_2O_3 content of a typical glass silica sand is now as low as 0.015% to 0.02% for flint glass manufacture and 0.1% to 0.15% for colored glass. Additionally, recycling of amber and green glass was substantially greater than flint glass and therefore lower grade deposits are in less demand.

Students and faculty at New York City-based Columbia University conducted research into glascrete with the objective to find a use for the roughly 100,000 tons of glass that city residents discard each year. The group hopes to develop stronger, longer-lasting concrete by adding certain types of glass. So far, the researchers have discovered that green glass strengthens and stabilizes concrete by minimizing a chemical reaction that takes place between the alkali in cement and the silica in certain aggregates (Engineering News Record, 1996c).

Besides glass, recycling of used foundry sands is also being researched. Neu Séchage Industriel, of D'Ussel, France, has developed a sand reconditioning system using natural gas combustion in a fluidized bed. The reconditioning process is based on heat treating the spent sand. This causes the additive resins to decompose and the oxidation of their base components to be converted into water vapor and carbon dioxide. A 95% recovery rate was reported (Journal of Metals, 1996).

On the negative side, recycling of silica refractories is hardly ever done. Because recycling these refractories requires crushing and grinding, silica dust is generated. The dust must be controlled according to hazardous material regulations and this makes the recycling prohibitively expensive.

International trends toward increased recycling of glass and foundries sands and innovative ideas on recycling other materials should influence greater recycling of silica products.

Transportation.—Of the total industrial sand and gravel produced, 61% was transported by truck from the plant to the site of first sale or use, down from 65% in 1995; 35% was transported by rail, up from 32% in 1995; 2% by waterway; and 1% was not transported. Because most of the producers did not

report shipping distances or cost per ton per mile, no transportation cost data were available.

Prices.—Compared with that of 1995, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased slightly to \$17.88 per metric ton. Average unit values for industrial sand and industrial gravel were \$18.51 and \$10.76 per ton, respectively. Nationally, ground industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton (\$112.10), followed by ground silica for molding and core facings (\$57.95), silica for well packing and cementing (\$51.33), ground silica sand used in ceramics (\$45.32), ground sand used for fiberglass (\$44.10), ground silica for scouring cleansers (\$43.75), and silica for swimming pool filters (\$43.00).

Industrial sand and gravel price changes were greatly mixed, some markets remained level, others had small increases or decreases, and still others experienced large increases or decreases. This situation was possible because although the silica was essentially the same, most markets were very independent from each other and price competition was influenced by availability, regulations and health concerns, and competition from other materials. Those end uses that sustained greater prices in 1996, compared with 1995, included: blasting, ceramics, fiberglass (ground), filtration, recreational, roofing granules and fillers, silicon carbide, and whole grain fillers. Silica for container and flat glass, fiberglass (whole grain), flux, frac, ground fillers, refractory, scouring cleansers, traction, and well packing and cementing experienced a decrease in unit value.

The average value per ton of industrial sand and gravel was highest in the South (\$19.23), followed by the West (\$18.47), the Northeast (\$18.31), and the Midwest (\$16.54). Prices can vary greatly for similar grades of silica at different locations in the United States. For example, glass sand average value per ton varied markedly, from \$19.03 in the West to \$12.24 in the Midwest. Tighter supplies and higher production costs in the West and much greater competition in the Midwest, caused the difference in the cost of sand and gravel in these two regions. (See table 6.)

Foreign Trade.—Exports of industrial sand decreased nearly 24% from 1995, but the associated value increased about 7%. Export distribution is as follows: 64% went to Canada, 15% went to Europe, 11% went to Mexico, 7% went to Asia, and the remainder went to Central and South America, the Middle East, and Oceania.

Imports for consumption of industrial sand dropped to 7,000 tons, which represents only 12% of the imports of 1995. Silica imports vary greatly from year to year but are always rather insignificant. Canada supplied 71% of the silica imports for 1996, averaging about \$107 per ton (including insurance and freight cost to the U.S. port). The total value of imports was \$1.5 million, with an average of \$214 per ton. Higher priced imports came from Australia, Belgium, Germany, Italy, Japan, Sweden, and the United Kingdom. (See tables 7 and 8.)

World Review.—World production of industrial sand and gravel, based on information usually provided by foreign

Governments, was estimated to be 117 million metric tons, slightly less than in 1995. The United States was the leading producer followed by, in descending order, the Netherlands, Germany, Austria, Paraguay, and France. Most countries in the world had some production and consumption of industrial sand and gravel because it is essential to the glass and foundry industries. However, because of the great variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed, several other countries were believed to have had some type of silica production and consumption. (*See table 9.*)

Current Research and Technology.—Most of the research and process development reported in 1996 concerned new types and uses of glass but other important work continued involving chemicals, ceramics, and advanced materials.

Owens Corning, of Toledo, OH, announced a new glass fiber product. Dubbed CRATEC Chopped Strand 173X-10C 4mm, it is designed to enhance the performance of polyamide composite polymers, especially in under-the-hood automotive applications (Functional Filler and Fiber Markets, 1996).

Pilkington PLC, St. Helens, United Kingdom, has developed a new process that promises to use greater amounts of silica and silicon. The new process enables a reflective multilayer sandwich of silicon and silica coatings to be applied continuously by chemical vapor deposition as the glass is being manufactured. The new mirrors will be able to withstand harsher and more humid environments than conventional silvered mirrors (Chemical and Engineering News, 1996a).

A chemist at Argonne National Laboratory and his colleagues are engineering an alkali-tin-silicate glass that does not deteriorate, as normal glass does, when plutonium is dissolved into it (Science News, 1996).

A treatment facility that immobilizes high-level nuclear wastes in glass has begun operations at the Federal Government's Savannah River site in South Carolina. The first stainless steel canisters, measuring 10 feet tall by 2 feet in diameter, were filled in March. There are 34 million gallons of radioactive waste which will fill about 6,000 canisters (Chemical and Engineering News, 1996c).

The first canister of vitrified radioactive waste at the Department of Energy's West Valley, NY, site was produced July 9, 1997. Over 600,000 gallons of high-level radioactive waste at the site will be mixed into a glass and poured into stainless steel canisters that are identical to the ones used in South Carolina. When finished, about 300 containers of vitrified radioactive material will be produced (Engineering-News Record, 1996e).

AlliedSignal Ceramic Components of Torrance, CA, has developed a new silicon nitride. The ceramic was produced in its ongoing program to develop a high-temperature in situ reinforced silicon nitride for heat engine applications. The new material meets most of the program goals (Ceramic Industry, 1996b).

Silicon wafer surfaces can be rendered bioactive by simple wet-etching techniques new research shows. The research suggests that silicon "biochips" might be developed to bond

directly with living soft tissue and bone, with potential use in invasive medical and biosensing applications, intelligent drug delivery systems, and other electronic prosthetic devices (Chemical and Engineering News, 1996b).

Researchers have discovered a new form of silica nanoparticle that aggregate into a novel spiderweb-like microstructure and give off a bright blue glow when irradiated with ultraviolet light. The material shows promise for use in catalytic membranes, optical devices that emit blue light, and as an agent to increase the viscosity of polymers. The silica nanoparticles are produced by laser vaporization of polycrystalline silicon in an oxygen-containing atmosphere (Chemical and Engineering News, 1996f).

PQ Corp., a producer of zeolites (derived partially from silica) and other silanes, reportedly is working on and has developed new siliceous builders and other forms of silicates. They have recently introduced new products to some of the detergent manufacturers and are awaiting their evaluations (Chemical and Engineering News, 1996e).

Dow Corning Corp., of Midland, MI, has introduced two new silicone surfactants to improve pesticide performance. The new surfactants improve the wetting, spreading, and uptake of post emergence herbicides and other foliar-applied insecticides and fungicides (Chemical Marketing Reporter, 1996a).

Outlook.—The forecast range of total U.S. demand in the year 2000 is expected to be 26 to 30 million metric tons for industrial sand and gravel. Probable demand is expected to be about 29 million tons. All forecasts are based on previous performances for this commodity within various end uses, contingency factors considered relevant to the future of the commodity, and forecast made by analysts and producers in the various markets.

Since 1987, annual demand for glass sand had fluctuated between 10.0 and 11.1 million tons. Shipments of glass containers were down 5.4% in 1996 from 1995. In the United States, there were 137 billion container units consumed in 1985 and 20% were glass containers. By 1995, 182 billion units were consumed in the United States and the glass percentage had dropped to 14%. The amount of sand consumed for container glass has generally decreased since 1985 mainly because some glass containers were being replaced by aluminum cans and plastic containers and also because the amount of glass being recycled was increasing. Additionally, many manufacturers of container glass were using thinner walls in glass containers, and this has lowered the amount of sand used. Glass container shipments were expected to be about 2% less in 1997 compared with 1996.

In reaction to the lessening demand for container glass, Anchor Glass, of Tampa, FL, announced the closure of their plants in Clifton, NJ, and Houston, TX. Anchor is the United States' third-largest manufacturer of glass containers. From 1990 through 1996, at least 14 container glass production plants have closed down in the United States, leaving 72 plants in the United States (Edwards and Harben, 1996).

In 1996, flat glass shipments fell 3% from 1995. This decrease occurred despite an increase in flat glass' primary

markets: housing, up 7.7%, and automobile production, up 2.2%. However, the rate of growth for nonresidential construction slowed in 1996 (Ceramic Industry, 1997).

Guardian Industries, of Auburn Hills, MI, progressed on an expansion of its automobile glass plant in Millbury, OH. When completed, the plant will produce 5.5 million square feet of laminated glass each year (Glass Industry, 1996).

American Video Glass Co., a partnership formed by Sony Electronics Inc., Corning Inc., and Asahi Glass America Inc., announced plans to build a \$300 million plant to manufacture television glass. The facility will be located on the site of Sony's Pittsburgh manufacturing center at Mount Pleasant, PA (Ceramic Bulletin, 1996).

Flat glass shipments are expected to be unchanged in 1997 compared with 1996 due to slowdown in housing starts and light vehicle sales. At the global level, world flat glass demand is forecast to grow over 4% per year to 2.4 billion square meters in 2000.

Growth prospects remain good for fiber and specialty glasses. A 1996 report from Business Communications Co. Inc., Norwalk, CT, forecasts that the total North American market for advanced and specialty glasses will exceed \$3.7 billion by 2000. Demand for glass fiber reinforcements used in advanced composite materials is expected to grow by 9.6% through 2000. Growth was also expected in the market for electronic displays, such as liquid crystal displays (Industrial Minerals, 1996).

Made with glass, carbon, or aramid fibers, composite materials are usually polymers with fiber reinforcements. Today, these composites are used in the aerospace and chemical industries and they resist corrosion, impacts, parasites, and chemicals. Future growth will likely occur through the replacement of traditional materials such as concrete and steel. However, a lack of national standards covering design and fabrication of composites present hurdles for this changeover (Engineering News Record, 1996a).

Total demand for glass sand is expected to grow slowly through 2000. Probable demand for glass sand for 2000 was forecast to be 11.5 million tons, with a range of 9.5 to 12.5 million tons.

The use of foundry sand is dependent mainly on automobile and light truck production. Another important factor for the future consumption of virgin foundry sand is the recycling of used foundry sand. The level of recycling, though not clear, is thought to be increasing. Other materials or minerals compete with silica as foundry sand but these other "sands" usually suffer a severe price disadvantage. Based on these factors: foundry activity (mainly auto related), competing materials, and recycling, the probable forecast for silica foundry sand consumption in 2000 is expected to be 7.0 million tons, and the demand range is expected to be 6 to 7.5 million tons.

Frac sand sales in 1996 were about equal to those of 1995. The Baker-Hughes' cumulative drilling rig count comparing year to year data shows that 1996 stayed ahead of 1995's rig count from late February through the end of the year and ended the year about 12% ahead of 1995's week-by-week comparison.

Although the greater rig activity in 1995 did not translate to greater frac sand sales, the trend towards increased activity throughout 1996 boded well for growth in frac sand sales. As has been the case when comparing oil and gas drilling, U.S. production of oil will likely suffer as imports continue to control a higher percentage of supply but natural gas production will likely maintain steady increases. Exports were an important market for frac sand as U.S. sand was shipped to locations throughout the world.

Based on these factors, demand is expected to grow slowly for this end use during the decade. Growth will be in response to strong exports and growing demand for natural gas but tempered by limited U.S. oil well demand. Probable demand for hydraulic fracturing sand for 2000 is expected to be 1.6 million tons, with a range of 1.4 to 1.7 million tons.

Even though the growth in semiconductor sales has slowed, the rate of growth is still near 20% annually, dropping from around 40% in recent years. Advanced Silicon Materials, Inc. announced plans for the construction of a \$400 million polycrystalline silicon plant near Butte, MT (Chemical Marketing Reporter, 1996b). Polycrystalline silicon is the type of silicon that is grown from silica chemicals and used for semiconductor applications.

Hemlock Semiconductors Corp. has announced a \$100 million expansion at its Hemlock, MI, plant. Hemlock plans to increase capacity at the plant by 40% to a total production of 5,000 tons of polycrystalline silicon per year (Chemical Marketing Reporter, 1996c).

Some semiconductor companies have reacted to the slowdown in semiconductor sales with slowdowns of their own. Micron Technology Inc., Boise, ID, has slowed the construction of its \$2.5 billion semiconductor plant in Lehi, UT, and will complete the project on a 3- to 5-year time frame. The plant was originally planned to be finished by September 1996, but in February, Micron announced the slowdown (Engineering News Record, 1996d).

Ceradyne Inc., of Costa Mesa, CA, has installed its second pressure sintering facility solely dedicated to fabricating the advanced technical ceramic, sintered reaction bonded silicon nitride. Products which can be produced range from small cutting tool inserts to large precision semiconductor equipment components (Ceramic Industry, 1996a).

For specialty silicas, the silica route will usually be through the chemical and silicon metal categories and it is expected that the chemical and silicon metal categories should see better than average growth, probably in the 2% to 4% annual growth range. This positive forecast would be tempered if the specialty silicas producers are using a silica source other than industrial sand and gravel. The process for each type of silica is highly variable and certainly not well advertised and therefore it is difficult to determine the natural source and the processing route for the silica or silicate. Kline and Co. Inc. reported that producers of specialty silicas are scrambling to increase global capacity in anticipation of rising demand. Through 2000, the global market for specialty silicas is expected to grow at least 4% per year.

The United States is the largest producer and consumer of

silica sand among the market economy countries and was self-sufficient in this commodity. Most of it is produced in the Eastern part of the United States, where the premier deposits and major markets are. A significant amount of silica sand is also produced in the West and Southwest, mostly in California and Texas. Domestic production is expected to continue to meet more than 99% of demand well beyond 2000. Imports, mostly from Australia, Canada, and Europe are expected to remain minor.

Because the unit price of silica sand is relatively low, except for a few end uses that required a high degree of processing, the location of silica sand deposits in relation to the market was an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supplied local markets with a limited number of products.

Several factors could affect supply-demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand. These substitutes, mainly polymers and ceramics, would likely increase demand for ground silica, which is used as a filler in plastics; for glass fibers, which are used in reinforced plastics; and for silica, either chemical, whole grain, or ground, which are used to manufacture ceramics. Also, increased efforts to reduce waste and increase recycling could hinder glass sand demand. However, with advances in high tech materials, silica sand may see increased consumption for fiber optics and other silicon and glass compounds. Although developments could cause demand for silica sand to decrease, the total value of production could increase because of the increased unit value of the more specialized sands.

An increase in the price of oil on the international market would stimulate domestic drilling and extraction from new and old oil deposits. This would increase demand for domestic hydraulic fracturing sand.

Concern over the use of silica as an abrasive due to health concerns and the imposition of stricter legislative and regulatory measures concerning silica exposure could decrease demands in many silica markets. Silica sand for use in the abrasive blast industry was being attacked as a health hazard as marketers of competing materials including garnet, slags, and olivine, pushed the use of their "safer" abrasive medium.

Development of more efficient mining and processing methods are expected to continue. This will enhance development of lower grade silica sand deposits closer to markets but not presently mined. Such developments are expected to increase silica sand reserves.

Tripoli

Tripoli, as broadly defined, is composed of extremely fine-grained crystalline silica in various stages of aggregation. Grain sizes usually range from 1 to 10 micrometers, but particles as small as 0.1 to 0.2 micrometers are common. Commercial tripoli contains 98% to 99% silica and minor amounts of

alumina (as clay) and iron oxide. Tripoli may be white or some shade of yellow, brown, or red depending on the percentage of iron oxide.

Production.—A USGS annual survey of producers indicates that the output of crude tripoli produced domestically in 1996 was 98,000 tons with an estimated value of \$4.1 million. In the United States, four firms are known to produce and/or process tripoli. Malvern Minerals Co., Garland County, AR, produces crude and finished material. Malvern also produces a black material from novaculite. American Tripoli Co. produces crude material in Ottawa County, OK, and finished material in Newton County, MO. Unimin Specialty Minerals Inc. in Alexander County, IL, produces crude and finished material. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processes rottenstone, a decomposed fine-grained siliceous shale purchased from local suppliers. All of the aforementioned firms responded to the USGS survey.

Consumption.—The 1996 USGS annual survey of producers indicates that sales/use of processed tripoli decreased slightly in quantity to 79,600 tons with a value of \$18.4 million. The large increase in value from 1995 to 1996 represents a correction reported by a producer and should not be interpreted as an actual sudden jump in the price of tripoli. Unfortunately, corrected data for previous years were not available.

Tripoli has unique applications as an abrasive due to its hardness and because its grain structure lacks distinct edges and corners. It is a mild abrasive, making it suitable for use in toothpaste and tooth polishing compounds, industrial soaps, and metal/jewelry polishing compounds. The automobile industry uses it in buffing and polishing compounds for lacquer finishing.

The end-use pattern for tripoli has changed significantly in the past 25 years. In 1970, nearly 70% of the processed tripoli was used as an abrasive. In 1996, about 80% of tripoli output was used as a filler and extender in paint, plastic, rubber, caulking compounds, and enamel.

Tripoli primarily is used as a filler and extender in paints. These applications may account for as much as 85% of the tripoli used as a filler and extender. In exterior latex paints, tripoli also aids in tint retention, durability, leveling, and flowability. In enamels, it eases application and improves sheen. The controlled grain/particle size of tripoli in paints improves dispersal and promotes a more uniform coating. Additionally, paints with tripoli resist chemical agents and wear better than those in which water-ground whittings and other softer or more reactive fillers are used.

Plastics, rubbers, and resins each account for about 5% of the tripoli used as a filler/extender. Tripoli is used extensively in plastics for electrical uses because of its dielectric characteristics and its effects on flexibility and compression properties. Its chemical resistance, weatherability, and resistance to salt spray also are important to its use in plastics. The physical properties of tripoli allow high loading in most compounds, but its abrasiveness results in high wear in extruding nozzles and molds. The same properties that make tripoli useful as a filler and extender in plastics makes it valuable to the rubber and resin industries.

Tripoli is almost entirely composed of crystalline silica, which can cause silicosis. Moreover, crystalline silica has been identified as a probable carcinogen by the International Agency for Research on Cancer and by other health research organizations. The OSHA is required to regulate materials containing more than 0.1% crystalline silica in accordance with its Hazard Communication Standard. Consequently, all tripoli shipments must be labeled by producers in compliance with OSHA regulations.

Price.—The average reported value of all tripoli sold or used in the United States was \$231 per ton in 1996. The average reported value of abrasive tripoli sold or used in the United States during 1996 was \$170 per ton; the average reported value of filler tripoli sold or used domestically was \$246 per ton.

Outlook.—Consumption patterns for tripoli are not expected to change significantly over the next several years. Most of the existing markets are well defined and the probability of new uses is low.

Special Silica Stone Products

Silica stone products are abrasive tools/materials such as hones, whetstones, oilstones, stone files, grindstones, grinding pebbles, tube-mill liners, and deburring media. These products are manufactured from novaculite, quartzite, and other microcrystalline quartz rock. However, this report excludes products fabricated from such materials by artificially bonding the abrasive grains.

Production.—In response to a USGS production survey, 12 domestic firms reported that they quarried certain silica materials and/or manufactured silica stone products during 1996. Arkansas accounted for most of the value and quantity of production reported. Plants in Arkansas manufacture oilstones, whetstones, files, and deburring/tumbling media. Elsewhere, grindstones were manufactured in Ohio and tumbling/grinding media were produced in Wisconsin.

The industry has produced four main grades of Arkansas whetstone in recent years. The grades range from the high-quality Black Hard Arkansas Stone down to the Washita Stone. In general, the Black Hard has a porosity of 0.07% and a waxy luster, while Washita Stone has a porosity of 16% and resembles unglazed porcelain.

Consumption.—The domestic consumption of special silica stone products is a combination of household, industrial, leisure, and craft uses. Major household uses include the sharpening of knives and other cutlery such as scissors, shears, and lawn and garden tools. Leading industrial uses include the sharpening and honing of cutting surfaces, polishing of metal surfaces, and the deburring of metal and plastic castings. Recreational uses include the sharpening of sports knives, arrowheads, spear points, and fish hooks. Craft applications include sharpening tools for wood carving, jewelry making, and engraving work. Also, silica stone files are used in the manufacture, repair, and modification of firearms.

Price.—The reported value of crude material suitable for cutting into finished products varied from \$229 per ton to

\$1,140 per ton in 1996. The average value was \$560 per ton. The average value of stone products made from crude material was \$4.22 per pound.

Foreign Trade.—Silica stone products exported in 1996 had a value of at least \$6.7 million. These exports were categorized as “hand sharpening and polishing stones” by the U.S. Department of Commerce, which collects trade data. This category accounted for most, if not all, of silica stone products exported in 1996.

The value of imported silica stone products in 1996 was at least \$2.96 million. These imports were hand sharpening and polishing stones, which accounted for most or all of imported silica stone products in 1996. A portion of the finished products that were imported may have been made from crude novaculite produced within the United States and exported for processing.

Outlook.—Consumption patterns for special silica stone are not expected to change significantly over the next several years. Most of the existing markets are well defined and the probability of new uses is low.

Quartz Crystals

Electronic-grade quartz crystal is single-crystal silica which has properties that make it uniquely useful for accurate frequency controls, timers, and filters in electronic circuits. These devices are utilized for a wide variety of electronic applications in communications equipment, computers, aerospace hardware, instruments for military/commercial uses (e.g., altimeters and navigational aids), and consumer goods (e.g., clocks, television receivers, and games/toys). Such uses generate practically all of the demand for electronic-grade quartz crystal. A lesser amount of optical-grade quartz crystal is used as windows and lenses in specialized devices including some lasers.

Natural quartz crystal primarily was used in electronic and optical applications until 1971, when it was surpassed by cultured quartz crystal. The use of natural quartz crystal for carvings and other gemstone applications continued; quartz crystal for such applications are covered in an annual Gemstones Mineral Industry Survey published by the USGS.

Legislation and Government Programs.—The strategic value of quartz crystal was demonstrated more than 50 years ago when it gained wide use as an essential component of military communication systems during World War II. After the war, natural electronic-grade quartz crystal was officially designated as a strategic and critical material for stockpiling by the Federal Government. Cultured quartz crystal, which eventually supplanted natural crystal in nearly all applications, was not commercially available when acquisition of the latter for a national stockpile began.

As of December 31, 1996, the National Defense Stockpile (NDS) contained about 236,000 pounds of natural quartz crystal with a reported market value of more than \$2.9 million. The stockpile has 11 weight classes for natural quartz crystal ranging from 200 grams to more than 10,000 grams. However, the stockpiled crystals primarily are in the larger weight classes.

The larger pieces are suitable as seed crystals for cultured quartz crystal production. In addition, much of the stockpiled crystals could be of interest to the specimen and gemstone industry. Little, if any, of the stockpiled material is likely to be utilized in the same applications as cultured quartz crystal.

As cultured quartz crystal displaced natural quartz crystal in most applications, the Federal Government continued to assess its stockpile goals for the latter material. In the latest reports on the inventory of stockpile material, no quartz crystals were designated for retention. However, based on the figures reported for 1995 and 1996, no sales of natural quartz crystal occurred in 1996. Previously, quantities sold from the group that contains individual crystals in the NDS inventory that weighed 10 kilograms or more and could be used as seed material to generate cultured quartz crystal. Brazil traditionally has been the source of such large natural crystals, but changes in mining operations have reduced its production to a very small output.

Production.—The USGS collects domestic production data for quartz crystal through a survey of the domestic industry. In 1996, the industry consisted of four cultured quartz crystal producers and one company that mined feed material, called lascas, for producing cultured crystal. Four of the five producers responded to the industry survey, representing over 95% of the lascas and cultured quartz crystal output shown in table 1.

Lascas Products, Jessieville, AR, is the only domestic company known to supply lascas for producing cultured quartz crystal. Coleman mined only during the summer months, but processed lascas throughout the year. After mining, crushing, and sizing, lascas is transported to the company's processing plant where operators rinse it in oxalic acid and then in deionized water to remove external contaminants. Finally, hand sorting, drying, and examination on a light table complete the necessary processing. The material is then shipped to cultured quartz crystal producers in 45-kilogram (100-pound) bags within 20,000-kilogram lots.

The following four U.S. companies produced cultured quartz crystal during 1996: Sawyer Research Products Inc. of Eastlake, OH; Thermo Dynamics Corp. of Merriam, KS; Motorola Inc. of Chicago, IL; and P. R. Hoffman Material Processing Co. of Carlisle, PA. Sawyer and Thermo Dynamics produced crystal bars for domestic and foreign firms in the crystal device fabrication industry. Motorola produced quartz crystal for internal consumption and domestic device fabricators. P.R. Hoffman reported external sales.

The aforementioned companies produce cultured quartz crystal using a hydrothermal process in large pressure vessels, known as autoclaves. Seed crystals (very thin crystals cut to exact dimensions) are mounted on racks and suspended in the upper growth region of the vessel. Lascas is loaded in an open-mesh wire basket that is placed in the bottom of the autoclave.

A solution of sodium hydroxide or sodium carbonate (the mineralizer), with additives such as lithium salts and deionized or distilled water is used to fill the vessel from 75% to 85% of its volume. The bottom half of the growing vessel is heated to temperatures averaging between 350° C to 400° C; the

temperature of the top portion is maintained at 5° C to 50° C less, depending on the mineralizer used. At these temperatures, the solution expands and creates an internal pressure in the vessel between 10,000 and 30,000 pounds per square inch. Under these conditions, the lascas dissolves to create a solution saturated with silica. Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed crystals in the top half of the autoclave. The process continues until the growing crystals reach their desired size. The process normally takes 30 to 60 days for a 1-inch thick bar and longer for other types of crystal; at least one producer has made runs of about 180 days. The cultured crystals can be custom grown with specific properties.

The processing of quartz crystal for various end uses is the same whether natural or cultured seed crystal is used. However, producers must avoid seed crystals with defects that would pass on to new generations of cultured crystal. Natural quartz crystal is preferred as seed material to ensure that genetic defects will not be repeated in the succeeding generations.

Once produced, cultured crystals are examined for physical defects before cutting. They are then cut, usually with diamond or slurry saws, along a predetermined crystallographic plane to a thickness slightly larger than that desired. Each wafer is inspected and diced into blanks of the desired dimensions. The blanks then progress through a series of lapping stages until they reach the final thickness; electrodes are attached and the crystals are mounted in suitable holders. The final assembly, called a quartz crystal unit, is ready for insertion into an electronic circuit.

Consumption.—The USGS collected 1996 domestic consumption data for quartz crystal through a survey of 30 U.S. operations in 11 States that fabricate quartz crystal devices. These companies represented virtually all of domestic consumption. Nineteen companies responded to the survey. Nonrespondent's consumption was estimated based on previous years' reports.

Quartz crystal is used in piezoelectric and optical applications. The piezoelectric effect is achieved when a suitable electrical signal applied to a quartz wafer makes the wafer vibrate mechanically throughout the bulk of the material at a characteristic natural resonance frequency. Quartz resonators are uniquely suitable for military, aerospace, and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate stability, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators also are used for many less demanding applications such as providing timing signals for electronic circuits in industrial, automotive, and consumer products.

Cultured quartz is used almost exclusively by the crystal device industry because of cost advantages. For resonator applications, raw quartz must be cut into thin wafers oriented precisely with the raw material crystal axes. The uniformity and convenience of cultured quartz have made its use almost

universal. Unlike cultured quartz, natural electronic-grade quartz requires special orientation, cutting, grading, and sizing to produce a quartz wafer. As a result, most device manufacturers that cut natural quartz in the past have discontinued its use. One of the remaining uses of natural electronic-grade material is in pressure transducers used in deep wells.

The quartz wafer must be cut too thinly for practical use at very high frequencies (above 100 megahertz). Quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than wafer thickness, have become more important at these higher frequencies. These structures are called surface acoustical wave devices.

Most optical applications use quartz in the fused form as silica glass. Relatively small quantities of cultured quartz crystal are used directly for special optical considerations. Quartz crystal also has uses involving normally polarized laser beams; quartz retardation plates (especially quartz wave plates), Brewster windows and prisms, birefringent filters, and tuning elements are utilized in laser optics.

Prices.—The average value of as-grown cultured quartz was \$49 per kilogram in 1996. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, was about \$117 per kilogram. (Also note market value cited above for natural quartz crystal in the NDS.)

Foreign Trade.—The U.S. Department of Commerce, which is the major government source of U.S. trade data, does not provide specific import or export statistics on lascar. Some lascar reportedly was imported from Africa (probably Namibia) and Brazil in 1995. Imports and exports of all electronic-grade quartz crystal are shown in table 1.

World Review.—Cultured quartz crystal production is concentrated in China, Japan, Russia, and the United States with several companies producing crystal in each country. Smaller production capacity exists in Belgium, Brazil, Bulgaria, France, Germany, South Africa, and the United Kingdom. Details concerning quartz operations in China, nations that formerly comprised the U.S.S.R., and Eastern European countries is unavailable. However, it is known that operations in Russia have significant capacity to produce synthetic quartz.

Outlook.—Demand for quartz crystal devices should continue to grow and, consequently, quartz crystal production should remain strong well into the future. Growth of the consumer electronics market (e.g., personal computers, electronic games, and cellular telephones) particularly in the United States, will continue to provide markets for domestic production. The growing global electronics market may require additional production capacity worldwide.

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TABLE 1
SALIENT U.S. SILICA STATISTICS 1/

		1992	1993	1994	1995	1996
Industrial sand and gravel: 2/						
Sold or used:						
Sand:						
Quantity	thousand metric tons	23,700	24,500	25,500	26,300	25,500
Value	thousands	\$415,000	\$436,000	\$466,000	\$480,000	\$473,000
Gravel:						
Quantity	thousand metric tons	1,520	1,700	1,790	1,880	2,240
Value	thousands	\$19,800	\$18,500	\$22,400	\$21,900	\$24,100
Total industrial:						
Quantity	thousand metric tons	25,200	26,200	27,300	28,200	27,800
Value	thousands	\$434,000	\$454,000	\$488,000	\$502,000	\$497,000
Exports:						
Quantity	thousand metric tons	1,340	1,750	1,880	1,870	1,430
Value	thousands	\$90,400	\$91,000	\$102,000	\$106,000	\$113,000
Imports for consumption:						
Quantity	thousand metric tons	164	44	24	59 r/	7
Value	thousands	\$2,450	\$2,440	\$1,790	\$2,730	\$1,500
Processed tripoli: 3/						
Quantity	metric tons	76,200	78,300	82,300	80,100	79,600
Value	thousands	\$14,100	\$15,500	\$10,900	\$10,500	\$18,400
Special silica stone:						
Crude production:						
Quantity	metric tons	1,730	528	873	979	1,290
Value	thousands	\$239	\$240	\$821	\$777	\$722
Sold or used:						
Quantity	metric tons	340	267	487	374	410
Value	thousands	\$4,550	\$3,770	W	W	\$3,810
Electronic and optical-grade quartz crystals:						
Production:						
Mine	thousand kilograms	778	454	544	435	435
Cultured	do.	407	394	294	351 r/	327

r/ Revised. W Withheld to avoid disclosing company proprietary data.

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Puerto Rico excluded from all industrial sand and gravel statistics.

3/ Includes amorphous silica and Pennsylvania rottenstone.

TABLE 2
INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION 1/

Geographic region	1995				1996			
	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	81	(2/)	\$1,560	(2/)	110	(2/)	\$1,770	(2/)
Middle Atlantic	2,400	9	42,900	9	2,280	8	42,000	9
Midwest:								
East North Central	10,400	37	161,000	32	10,200	37	159,000	32
West North Central	1,900	7	41,000	8	1,820	7	39,800	8
South:								
South Atlantic	4,070	14	76,300	15	3,820	14	73,400	15
East South Central	1,470	5	22,300	4	1,620	6	23,900	5
West South Central	4,110	15	84,600	17	4,100	15	86,300	17
West:								
Mountain	1,790	6	28,400	6	1,820	7	24,800	5
Pacific	1,960	7	44,000	9	2,010	7	46,000	9
Total	28,200	100	502,000	100	27,800	100	497,000	100

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Less than 1/2 unit.

TABLE 3
INDUSTRIAL SAND AND GRAVEL SOLD OR USED
IN THE UNITED STATES, BY STATE 1/

(Thousand metric tons and thousand dollars)

State	1995		1996	
	Quantity	Value	Quantity	Value
Alabama	479	5,940	799	8,380
Arizona	334	2,910	323	2,890
Arkansas	W	W	W	W
California	1,710	38,300	1,760	40,500
Colorado	W	W	W	W
Florida	547	6,340	515	6,340
Georgia	574	7,060	313	5,650
Idaho	501	8,720	646	8,510
Illinois	4,410	67,500	4,460	66,400
Indiana	W	W	W	W
Iowa	W	W	W	W
Kansas	W	W	W	W
Louisiana	572	10,500	706	12,100
Maryland	W	W	W	W
Massachusetts	--	--	W	W
Michigan	2,940	30,600	2,680	29,400
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	W	W	W	W
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	W	W	W	W
New Jersey	1,760	31,000	1,680	30,300
New York	W	W	W	W
North Carolina	1,330	21,900	1,500	21,700
North Dakota	W	W	W	W
Ohio	1,270	28,800	1,270	29,800
Oklahoma	1,250	25,400	1,350	27,200
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	839	20,500	761	19,500
Tennessee	918	14,700	747	13,900
Texas	1,600	40,300	1,420	38,200
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,670	33,300	1,660	32,300
Other	5,500	109,000	5,190	104,000
Total	28,200	502,000	27,800	497,000

W Withheld to avoid disclosing company proprietary data; included with "Other."

1/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 4
INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED
STATES IN 1996, BY SIZE OF OPERATION 1/

Size range	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total
Less than 25,000	26	18	238	1
25,000 to 49,999	15	10	533	2
50,000 to 99,999	26	18	1,670	6
100,000 to 199,999	30	21	3,820	14
200,000 to 299,999	14	10	3,150	11
300,000 to 399,999	7	5	2,270	8
400,000 to 499,999	10	7	4,050	15
500,000 to 599,999	6	4	2,940	11
600,000 to 699,999	5	3	2,910	10
700,000 and over	7	5	6,200	22
Total	146	100	27,800	100

1/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 5
NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1996,
BY GEOGRAPHIC REGION

Geographic region	Mining operations on land			No plants or unspecified	Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable			
Northeast:						
New England	1	--	--	--	1	2
Middle Atlantic	9	--	2	1	4	16
Midwest:						
East North Central	33	--	--	1	4	38
West North Central	5	--	--	--	6	11
South:						
South Atlantic	16	--	1	3	5	25
East South Central	9	--	--	--	2	11
West South Central	8	--	--	2	11	21
West:						
Mountain	7	2	2	--	--	11
Pacific	8	1	1	--	1	11
Total	96	3	6	7	34	146

TABLE 6
INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1996, BY MAJOR END USE 1/

Major use	Northeast			Midwest			South			West			U.S. total		
	Quantity (thousand metric tons)	Value (thousands)	Value per ton 2/	Quantity (thousand metric tons)	Value (thousands)	Value per ton 2/	Quantity (thousand metric tons)	Value (thousands)	Value per ton 2/	Quantity (thousand metric tons)	Value (thousands)	Value per ton 2/	Quantity (thousand metric tons)	Value (thousands)	Value per ton 2/
Sand:															
Glassmaking:															
Containers	860	\$14,900	\$17.28	1,620	\$17,000	\$10.54	1,610	\$23,800	\$14.75	1,100	\$21,700	\$19.78	5,180	\$77,300	\$14.92
Flat (plate and window)	W	W	16.24	923	10,300	11.19	1,520	22,800	14.95	W	W	16.74	2,980	42,000	14.09
Specialty	W	W	22.48	368	5,630	15.29	327	6,150	18.82	W	W	30.74	928	17,200	18.52
Fiberglass (unground)	W	W	13.46	459	6,390	13.93	193	4,030	20.88	W	W	18.21	825	13,300	16.11
Fiberglass (ground)	--	--	--	W	W	49.35	379	16,500	43.55	W	W	27.67	431	19,000	44.10
Foundry:															
Molding and core	347	6,590	18.98	5,070	62,100	12.26	970	13,500	13.97	76	1,630	21.42	6,460	83,900	12.98
Molding and core facing (ground)	--	--	--	W	W	57.95	--	--	--	--	--	--	W	W	57.95
Refractory	W	W	31.00	49	557	11.37	W	W	48.38	W	W	23.43	58	981	16.91
Metallurgical:															
Silicon carbide	--	--	--	84	2,210	26.33	--	--	--	--	--	--	84	2,210	26.33
Flux for metal smelting	--	--	--	--	--	--	W	W	2.00	W	W	5.88	W	W	5.82
Abrasives:															
Blasting	140	3,780	26.98	205	4,650	22.70	969	21,700	22.38	152	5,010	32.93	1,470	35,100	23.96
Scouring cleansers (ground)	--	--	--	W	W	45.14	W	W	34.00	--	--	--	W	W	43.75
Sawing and sanding	W	W	19.00	W	W	13.00	W	W	18.75	--	--	--	W	W	17.67
Chemicals (ground and unground)	W	W	18.90	W	W	12.45	234	5,850	25.01	52	1,050	20.15	643	12,000	18.63
Fillers (ground):															
Rubber, paints, putty, etc.	--	--	--	115	6,070	52.78	W	W	217.80	W	W	29.71	192	21,500	112.10
Whole grain fillers/building products	61	1,470	24.03	488	15,600	31.90	406	9,840	24.23	271	7,310	26.99	1,230	34,200	27.90
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	31.00	146	6,950	47.60	122	5,340	43.73	W	W	37.00	278	12,600	45.32
Filtration:															
Water (municipal, county, local, etc.)	59	1,670	28.31	80	2,060	25.74	99	1,110	11.23	73	2,700	36.96	310	7,540	24.32
Swimming pool, other	W	W	59.29	W	W	58.00	36	1,210	33.64	--	--	--	54	2,320	43.00
Petroleum industry:															
Hydraulic fracturing	--	--	--	1,150	37,900	33.01	W	W	31.38	W	W	31.30	1,530	49,900	32.62
Well packing and cementing	W	W	58.33	17	1,110	65.00	W	W	15.14	--	--	--	27	1,390	51.33
Recreational:															
Golf course (greens and traps)	100	1,440	14.42	218	3,320	15.23	214	2,510	11.71	163	3,250	19.95	694	10,500	15.16
Baseball, volleyball, play sand, beaches	93	921	9.90	8	116	14.50	28	344	12.29	36	800	22.22	165	2,180	13.22
Traction (engine)	W	W	14.06	133	854	6.42	120	1,530	12.74	W	W	19.90	307	3,280	10.68
Roofing granules and fillers	90	1,440	15.94	41	707	17.24	153	2,270	14.83	45	698	15.51	330	5,110	15.48
Other (ground silica)	9	279	31.00	W	W	34.12	W	W	16.75	46	1,000	19.26	XX	XX	XX
Other (whole grain)	601	10,500	6.09	559	7,360	11.93	811	17,000	12.03	1,060	18,000	23.96	XX	XX	XX
Total or average	2,360	42,900	18.21	11,800	196,000	16.54	8,280	171,000	20.65	3,070	63,100	20.53	25,500	473,000	18.51
Gravel:															
Silicon, ferrosilicon	--	--	--	W	W	23.40	W	W	12.43	--	--	--	686	9,400	13.70
Filtration	W	W	34.57	W	W	11.02	82	816	9.95	--	--	--	188	2,480	13.19
Nonmetallurgical flux	--	--	--	--	--	--	W	W	6.89	W	W	10.20	946	8,700	9.20
Other uses, specified	W	W	10.60	21	185	8.81	285	2,200	7.71	W	W	10.04	420	3,530	8.41
Total or average	31	832	26.84	183	2,950	16.10	1,260	12,600	9.94	762	7,760	10.18	2,240	24,100	10.76
Grand total or average	2,390	43,800	18.31	12,000	198,000	16.54	9,550	184,000	19.23	3,830	70,800	18.47	27,800	497,000	17.88

W Withheld to avoid disclosing company proprietary data; included in "U.S. Total" and/or "Total or average." XX Not applicable.

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Calculated using unrounded data.

TABLE 7
U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY 1/

(Thousand metric tons and thousand dollars)

Country	1995		1996	
	Quantity	F.a.s. value 2/	Quantity	F.a.s. value 2/
North America:				
Bermuda	(3/)	5	--	--
Canada	1,430	20,200	914	17,100
Mexico	129	5,270	136	9,300
Panama	12	172	15	254
Other	9	616	7	1,420
Total	1,580	26,200	1,070	28,000
South America:				
Argentina	9	1,210	8	1,140
Brazil	2	948	1	580
Peru	2	224	1	258
Venezuela	5	857	3	518
Other	3	432	17	580
Total	21	3,670	30	3,080
Europe:				
Germany	41	13,700	35	14,100
Italy	4	2,350	4	866
Netherlands	49	9,630	10	6,750
United Kingdom	6	1,960	4	1,970
Other	22	5,050	165	9,390
Total	122	32,700	218	33,100
Asia:				
Hong Kong	9	2,030	20	1,930
Japan	52	24,400	36	29,300
Korea, Republic of	12	3,800	16	4,360
Singapore	8	4,400	6	3,630
Taiwan	53	5,740	17	3,510
Other	8	1,880	7	3,240
Total	142	42,200	102	46,000
Middle East and Africa	3	824	6	2,050
Oceania:				
Australia	1	644	2	1,160
Other	(3/)	28	1	45
Total	1	672	3	1,200
Grand total	1,870	106,000	1,430	113,000

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

3/ Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL SAND, BY COUNTRY 1/

(Thousand metric tons and thousand dollars)

Country	1995		1996	
	Quantity	C.i.f. value 2/	Quantity	C.i.f. value 2/
Australia	56 r/	1,580	(3/)	63
Belgium	(3/)	36	(3/)	5
Canada	1	146	5	536
Germany	(3/)	r/ 301	(3/)	163
Guyana	(3/)	12	--	--
Italy	--	--	(3/)	11
Japan	(3/)	218	(3/)	346
Mexico	--	--	(3/)	4
Russia	(3/)	6	--	--
Sweden	1	403	1	265
United Kingdom	(3/)	17	(3/)	51
Venezuela	(3/)	11	(3/)	56
Total	59 r/	2,730	7	1,500

r/ Revised.

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.

3/ Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY 1/ 2/

(Thousand metric tons)

Country 3/	1992	1993	1994	1995	1996 e/
Argentina	340	396	247 r/	286 r/	290
Australia e/	2,000	2,000	2,500	2,500	2,500
Austria	5,884	4,302	6,457	7,503	7,000
Belgium e/	2,480	2,480	2,480	2,500	2,300
Bosnia and Herzegovina	50	50	50	50 e/	50
Brazil e/	2,700	2,700	2,700	2,700	2,700
Canada	1,754	1,600 e/	1,600 e/	1,689 r/	1,668 p/
Chile e/	300	300	300	300	300
Croatia	40	23	31 r/	341 r/	44 4/
Cuba e/	450	400	300	300	300
Czech Republic	XX	1,758	1,957	1,993	1,900
Czechoslovakia 5/	2,010	XX	XX	XX	XX
Denmark (sales) e/	315	315	315	50 r/	50
Ecuador	36 r/	49 r/	34 r/	36 r/	36
Egypt e/ 6/	500	500	500	500	500
Estonia e/	30	25	25	25	25
Finland	169	167	72	75 e/	75
France e/	6,300	5,400	7,280	6,100 r/	6,500
Germany	10,706	9,768	10,840	7,600 r/	7,500
Guatemala e/	34 4/	27	27	29	30
Hungary 7/	1,350	440	512	320 r/	325
Iceland e/	5	5	5	5	4
India	1,316	1,148	1,252 r/	1,220 r/	1,250
Indonesia	400 e/	240	588 r/	279 r/	300
Iran 8/	756	932	950 e/	1,000 e/	1,000
Ireland e/	7	7	8	7	6
Israel e/	60	60	60	60	60
Italy e/	4,000	3,100 r/	2,700 r/	3,000 r/	3,000
Jamaica	20	21	18	20 e/	20
Japan	3,843	3,883	3,942	3,734 r/	3,557 4/
Kenya e/	12	12	12	12	12
Korea, Republic of e/	2	2	2	2	2
Latvia	110 e/	90 e/	76	64 r/	50

See footnotes at end of table.

TABLE 9--Continued
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY 1/ 2/

(Thousand metric tons)

Country 3/	1992	1993	1994	1995	1996 e/
Malaysia	579	355	231	288	269 4/
Mexico	1,129	1,310	1,360	1,293	1,469 4/
Netherlands	20,000 e/	20,000 e/	25,006	23,159 r/	24,000
New Caledonia e/	31	31	39	40	40
New Zealand	72 r/	49 r/	38 r/	31 r/	30
Norway	900 e/	900 e/	891 r/	963 r/	900
Pakistan	135	168	170 e/	170 e/	165
Panama e/	23 4/	23	23	23	23
Paraguay e/	2,000 r/	2,000 r/	2,000 r/	7,000 r/	7,000
Peru	152	115	100	100	100
Philippines	744	828	800 e/	800 e/	800
Poland	931	1,020	911	952	900
Portugal e/	5	5	5	5	5
Serbia and Montenegro	922	270	403	308 r/	300
Slovenia	310	210	210	210 e/	200
South Africa	1,750	1,738	1,920	2,180	2,167 4/
Spain	2,178	2,506 r/	2,577 r/	2,881 r/	2,800
Sweden e/	1,433 4/	1,500	1,500	1,500	1,500
Tanzania e/	4 4/	4	4	--	--
Thailand	594	459	471	326 r/	350
Turkey e/ 9/	510	350	415	310 r/	350
United Kingdom	3,615	4,000 e/	4,038 r/	3,600 e/	2,000
United States (sold or used by producers)	25,200	26,200	27,300	28,200	27,800 4/
Venezuela	703	753	141	598	748 4/
Zimbabwe 10/	77	61 r/	89 r/	174 r/	150
Total	112,000	107,000 r/	119,000	119,000	117,000

e/ Estimated. p/ Preliminary. r/ Revised. XX Not applicable.

1/ Table includes data available through July 2, 1997.

2/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

3/ In addition to the countries listed, Angola, Antigua and Barbuda, The Bahamas and China, among others, produce industrial sand, but current available information is not adequate to formulate estimates of production levels.

4/ Reported figure.

5/ Dissolved Dec. 31, 1992. All production for 1992 came from Czech Republic.

6/ Fiscal years beginning July 1 of that stated.

7/ For the reported volumetric quantity, see the U.S. Geological Survey Minerals Yearbook 1996, v. III.

8/ Fiscal years beginning Mar. 21 of that stated.

9/ Washed product.

10/ Includes rough and ground quartz as well as silica sand.

TABLE 10
PROCESSED TRIPOLI 1/ 2/ SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1992	1993	1994	1995	1996
Abrasives metric tons	18,600	19,400	39,000	19,300	W
Value thousands	\$2,780	\$2,960	\$5,170	\$2,920	W
Filler 3/ metric tons	57,600	58,900	42,800	60,700	W
Value thousands	\$11,300	\$12,600	\$5,640	\$7,580	W
Total quantity metric tons	76,200	78,300	82,300	80,100	79,600
Total value thousands	\$14,100	\$15,500	\$10,900	\$10,500	\$18,400

W Withheld to avoid disclosing company proprietary data.

1/ Includes amorphous silica and Pennsylvania rottenstone.

2/ Data are rounded to three significant digits; may not add to totals shown.

3/ Includes silica used in brake lining manufacturing.

TABLE 11
U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1996

Company and location	Type of operation	Product
Arkansas Abrasives, Inc., Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Blue Mountain Whetstone Co., Hot Springs, AR	do.	Do.
Buffalo Stone Corp., Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media deburring media.
Cleveland Quarries Co., Amherst, OH	Stone cutting and finishing	Grindstones.
Gary Coleman, Jessierville, AR	Quarry	Crude novaculite.
Crow Stone Co.:		
Percy, AR	do.	Whetstones and oilstones.
Do.	do.	Crude novaculite.
Dan's Whetstone Co., Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Hall's Arkansas Oilstones, Inc., Percy, AR	Stone cutting and finishing	Whetstones and oilstones.
The Kraemer Co.:		
Baraboo, WI	Crushing and sizing	Deburring media.
Do.	Quarry	Crude silica stone.
Norton Company Oilstones:		
Hot Springs, AR	do.	Do.
Littleton, NH	Stone cutting and finishing	Whetstones and oilstones.
Smith Abrasives, Inc.:		
Hot Springs, AR	do.	Do.
Do.	Quarry	Crude novaculite.
Taylor Made Crafts, Lake Hamilton, AR	Stone cutting and finishing	Whetstones and oilstones.

TABLE 12
SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS 1/

(Thousand kilograms and thousand dollars)

	1992	1993	1994	1995	1996
Production:					
Mine	778	454	544	435	435
Cultured	407	394	294	351 r/	327
Exports (cultured): 2/					
Quantity	15	24	38	35	89
Value	\$1,280	\$2,260	\$6,110	\$10,900	\$22,200
Imports (cultured): 2/					
Quantity	6	8	19	47	42
Value	\$1,130	\$2,250	\$5,950	\$10,800	\$9,480
Apparent consumption e/	398	378	275	363 r/	280

e/ Estimated. r/ Revised.

1/ Data are rounded to three significant digits.

2/ Excludes mounted piezoelectric crystals.

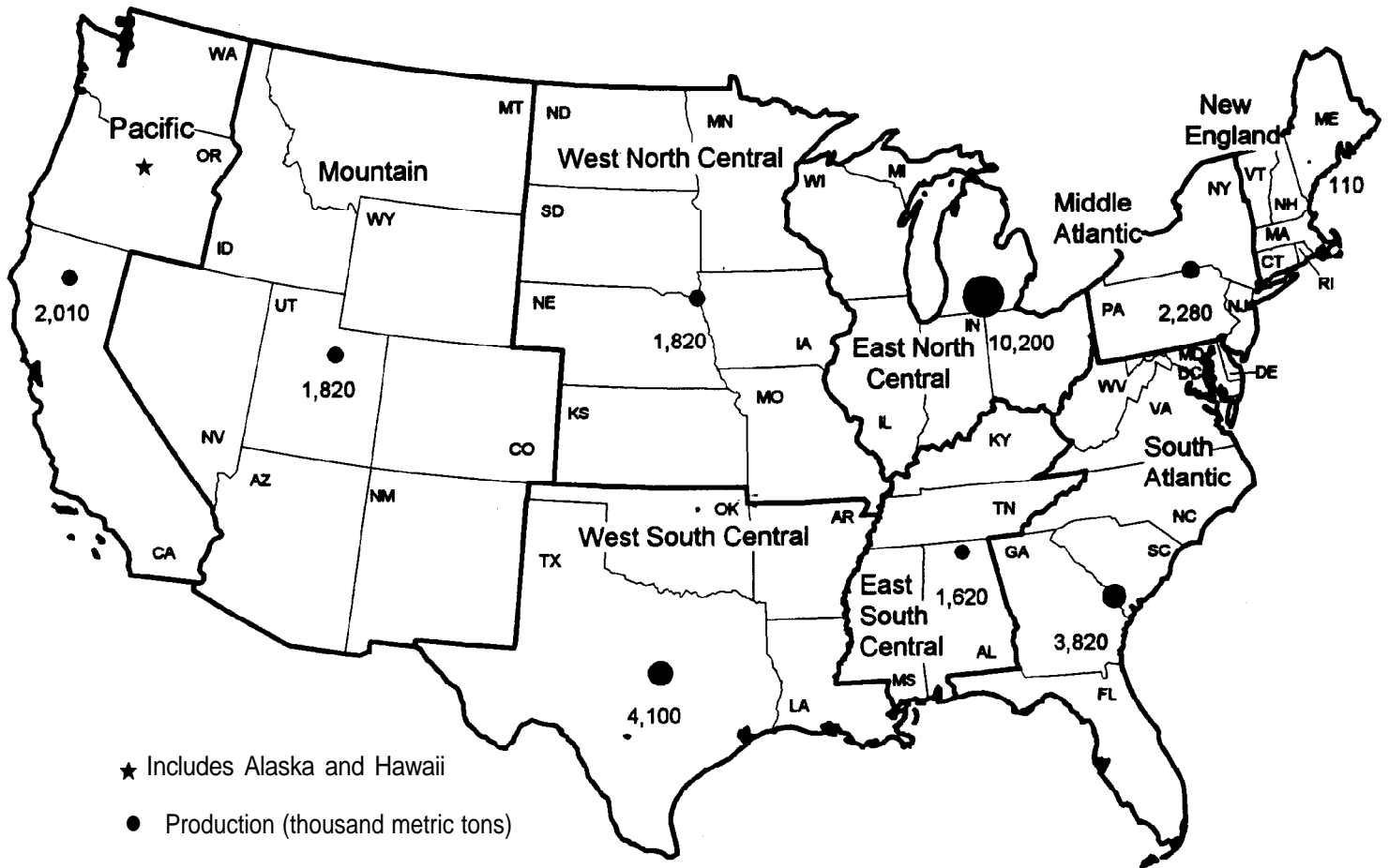


Figure 1 - Production of industrial sand and gravel in the United States in 1996, by geographic division