SILICA

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Four silica categories are covered in this report—industrial sand and gravel, quartz crystals, special silica stone products, and tripoli. Most of the stone covered in the special silica stone products section is novaculite. The section on tripoli includes tripoli and other fine-grained, porous silica materials that have similar properties and end uses, such as rottenstone. Certain silica and silicate materials, such as pumice and diatomite, are covered in other chapters of the U.S. Geological Survey (USGS) Minerals Yearbook.

Industrial Sand and Gravel

Total industrial sand and gravel production decreased slightly to 28.2 million metric tons in 1998 compared with that of 1997 (table 1). Compared with those of 1997, industrial sand production was up slightly, and gravel production dropped by nearly 18%. Exports increased dramatically, with 1998 exports nearly 2.5 times those of 1997; although imports were still minor, they increased to 44,000 metric tons.

Industrial sand and gravel, often termed "silica," "silica sand," and "quartz sand," includes sands and gravels with high silicon dioxide (SiO_2) content. These sands are used in glassmaking; for foundry, abrasive, and hydraulic fracturing applications; and for many other uses. The specifications for each use vary, but silica resources for most markets are abundant. In almost all cases, silica mining uses open pit or dredging mining methods with standard mining equipment. Except for temporarily disturbing the immediate area while mining operations are active, sand and gravel mining usually has little environmental impact.

Production decreases were the result of slackening demand for sand for many uses, including blasting, fiber (whole grain) and specialty glass, foundry, and hydraulic fracturing. The demand for silica gravel, which is used for the production of silicon and ferrosilicon, filtration, and nonmetallurgical flux, also significantly decreased.

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. One of the most important issues to have had an impact on the industrial minerals industry in recent times has been the question of crystalline silica and its effect on human health. Central to the ongoing and often heated debate has been the understanding and implementation of the measurements, the regulations, and the actions taken with regard to exposure to crystalline silica and, most significantly, appreciation of its impact on the future of many industries (Industrial Minerals, 1998b).

The Mine Safety and Health Administration issued an interim sampling policy for noise and contaminants, which directs inspectors to focus on mines where the likelihood of overexposure is reasonable. Among the priorities identified are operations producing cristobalite, ground silica, industrial sand, and other contaminants "that require proper work practices and maintenance of controls to ensure compliance" (Rock Products, 1998c).

U.S. and Japanese negotiators met in May to review the 1995 pact on flat glass. The United States secured Japan's commitment to implement new rules that should increase the use of insulating glass, but could not secure promises on antimonopoly compliance (Glass Magazine, 1998b).

Production.—Domestic production data for industrial sand and gravel were derived by the USGS from a voluntary survey of U.S. producers. The USGS canvassed 80 producers with 147 operations known to produce industrial sand and gravel. Of the 147 operations surveyed, 136 (93%) were active, and 11 were idle. Of the surveyed operations, 112 reported to the USGS, and their combined production represented about 86% of the U.S. total. Production for the 35 nonrespondents was estimated on the basis of previously reported information or other factors.

The Midwest Region (East North Central and West North Central Divisions) continued to lead the Nation with about 40% of the 28.2 million tons of industrial sand and gravel produced in the United States, followed by the South (South Atlantic, East South Central, and West South Central Divisions) with about 37%, and the West (Pacific and Mountain Divisions) with 13% (figure 1 and table 2).

The six leading producing States, in descending order, were Illinois, Michigan, New Jersey, Texas, Wisconsin, and California (table 3). Their combined production represented one half of the national total. Notable production changes took place in all these States, except Illinois, which was virtually unchanged from 1997 to 1998. Of the 36 States producing in 1998, 18 stayed about even, 10 had increased production, and 8 had decreased production compared with 1998. Georgia, New Jersey, and Pennsylvania reported the largest increases, and Michigan, Minnesota, and North Carolina reported the largest decreases.

About 78% of the total industrial sand and gravel was produced by 50 operations, each with an annual production of more than 200,000 tons (tables 4 and 5). The 10 leading producers of industrial sand and gravel, in descending order, were, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., Oglebay Norton Industrial Sands Co., Badger Mining Corp., Nugent Sand Co., Inc., Simplot Industries Inc., Short Mountain Silica Co., Construction Aggregates Corp., and Owens-Illinois, Inc. Their combined production from 56 operations represented 73% of the U.S. total.

Fairmount Minerals acquired Wexford Sand Co. from Sargent Sand Co., Saginaw, MI. Wexford produced lake sand primarily for the automotive casting industry in Michigan and Ohio. The deposit in Harrietta, MI, contains more than 25 years of reserves, according to Fairmount Minerals (Rock Products, 1998a).

Oglebay Norton bought Colorado Silica Sand, Inc., Colorado Springs, from Cardium Service and Supply Ltd; the acquisition included production facilities in Brady, TX. This was reported to have happened in 1997, but the purchase was actually finalized on March 9, 1998. Colorado Silica was founded in 1978 as a hydraulic fracturing (frac) sand supplier. The Colorado Springs deposit is an aeolian, highly siliceous, round, and spherical sand of Holocene age. The sand has been sold to numerous markets, including environmental, landscape, petroleum, recreation, water and wastewater filtration, and water well. Traditionally, Colorado Silica has supplied international and U.S. markets.

White Sands Mining Co. was added to the survey for 1998. The mine, near Elizabeth, IN, was formerly run by U.S. Silica and before that by Card Silica Company. White Sands is a division of Sand Trap Co.

Operations removed from the 1998 survey include Sargent Sand's Vasser sand plant, which the company reported went out of business in November 1997. Rhodia Inc., formerly Rhone-Poulenc Basic Chemicals, Inc., reported the closure of the Maiden Rock silica pit in 1996. They were thought to have been idle in 1997. Rhodia had produced silica as a nonmetallurgical flux for elemental phosphorus. South State Inc., Bridgeton, NJ, reported the closure of their operation in Gloucester County.

U.S. Silica acquired George F. Pettinos, Inc., a Pennsylvania-based producer and also a coater of silica sand for the construction industry and a reseller of a variety of other products for the foundry industry (Ceramic Industry, 1998g).

Northeast.—Cumberland County, NJ, continued to be the largest source for 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 most of the abrasive blast sand in the region. Whibco, Inc.'s operation, also in Cumberland County, was a major producer of foundry sand in the region.

Midwest.—Unimin's plants in La Salle and Ogle Counties, IL, Le Sueur County, MN, and Columbia County, WI, were among the leaders in producing sand for all four major markets—blast, foundry, hydraulic fracturing, 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, was a major supplier for the glass and foundry markets, and their St. Louis County, MO, operation was a large producer for the glass market. Other major producers for the foundry industry were Construction Aggregates, Ottawa County, MI, Nugent Sand, Muskegon County, MI, and Wexford Holding Co., Wexford County, MI. Badger Mining, Jackson and Green Lake Counties, WI, was a major producer for the foundry and hydraulic fracturing markets.

South.—Unimin and U.S. Silica 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, and Frederick County, VA. U.S. Silica's plants were in Bullock County, AL, Johnston County, OK, Lexington County, SC, Limestone County, TX, and Morgan County, WV. Cobb Industrial Corp., Red River Parish, LA, TEC Minerals Co., Liberty County, TX, Huey Stockstill Inc., Pearl River County, MS, Mid-State Sand and Gravel Co., Allen and East Baton Rouge Parishes, LA, and Specialty Sand Co., Colorado, Harris, and Newton Counties, TX, were large producers of blasting sand. B.V. Hedrick Gravel and Sand Co. and W.R. Bonsal and Co., Anson County, NC, Elmore Sand and Gravel, Inc., Elmore County, AL, and Martin Marietta Aggregates, Montgomery and Macon Counties, AL, produced a large percentage of the industrial gravel used in the production of silicon and ferrosilicon. Oglebay Norton, McCulloch County, TX, was the largest producer of frac sand and an important contributor of blast sand for the region. Whibco, Kershaw County, SC, was a significant producer of foundry sand. APAC Arkansas Inc., Muskogee County, OK, and Short Mountain Silica, Hawkins County, TN, were important producers of glass sand.

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

Consumption.—Sand and gravel production reported by producers to the USGS was material used by the companies or sold to their customers. Stockpiled material is not reported until consumed or sold. Of the 28.2 million tons of industrial sand and gravel sold or used, nearly 39% was consumed as glassmaking sand, and 22%, as foundry sand (table 6). Other important uses were abrasive sand (5.3%) and hydraulic fracturing sand (4.1%).

Exploitable resources of industrial sand and gravel occur throughout the United States, and successful mining companies are responding to market locations, which have traditionally been in the Eastern United States. Occasionally, consuming industries are specifically located near a silica resource. Because of the abundance of silica deposits, locating near a silica source was not always a priority, although it certainly was a consideration. The auto industry was originally located in the Midwest near clay, coal, iron, and silica resources. Therefore, foundry sands have been greatly exploited in Illinois, Indiana, Michigan, Ohio, and other Midwestern States. In 1998, nearly 80% of foundry sand was produced in the Midwestern region.

Conversely, the glass industry, had to locate plants where it could minimize the shipping distance of finished glass products. Hence, glass plants were more evenly distributed. In 1998, 40% of glass sand was produced in the South; 32%, in the Midwest; 16%, in the West; and 12%, in the Northeast. To varying degrees, all silica production and sales are similarly influenced by the location of the consuming industries.

The share of silica sold for all types of glassmaking as a percentage of all silica sold was 38.6%. This is slightly more than that of 1997 and was attributable to increased sales of silica for container and flat glass production. In 1998, sales to container glass manufacturers increased by 2.6% compared with those of 1997. This increase represents the second consecutive year of improvement in sand sales for glass container production since sales began falling in 1989 (from more than 7.3 million tons in 1988 to 5.2 million tons in 1996).

The U.S. glass container industry has consolidated greatly during the past 10 to15 years. In 1998, only three major companies supplied a wide range of glass containers. The consolidation was in response to fierce competition from other packaging materials and the immense purchasing power of the very large brewing groups that dominate the North American beer industry (Industrial Minerals, 1998g).

Some reports of a shortage of cullet (postconsumer glass and scrap glass) may have caused the greater demand for silica sand for container glass manufacture. Glass container production rose to 256 million in 1998 from 247 million in 1997. Especially during the past several decades, sales of glass containers have been adversely affected by competition from metals, plastics, and other packaging materials. Cullet can also be used in fiberglass and replaces some virgin silica. Miller Brewing Co. launched an expanded test of plastic beer bottles for three of its brands. The specially developed plastic containers were claimed to be recyclable and to offer the same 4-month shelf life as glass bottles (Glass Industry, 1998l). Also contributing to the decrease in domestic glass container sales, imported glass containers supplied 9.2% of domestic consumption in 1998 (U.S. Bureau of Census, July 1999, Glass containers—1998 summary, accessed August 12, 1999, at URL http://www.census.gov/ftp/pub/industry/1/m32g9813.pdf).

Ball-Foster Glass Container Co. added a state-of-the-art 480-metric-ton-per-day furnace to its plant at Dunkirk, IN. The furnace was operational in the third quarter of 1998 and will be used to melt amber and flint glasses (Glass Industry, 1998k).

Flat glass continued to be a good growth prospect for silica sales. In 1998, sales of sand for flat glass production increased by nearly 4% compared with those of 1997. Demand for flat glass in 1998 was expected to be about 3% above 1997 levels. Key drivers for U.S. flat glass demand was residential repair and remodeling and consumer durable expenditures (Ceramic Industry, 1998b).

Guardian Industries Corp. opened a state-of-the-art float plant in Geneva, NY, in early 1998. The Geneva plant took 13 months to build and produced 600 tons per day of glass. The plant produced clear float glass for the Northeast and Canada and is positioned to integrate with five surrounding Guardian fabricating plants (Glass Magazine, 1998a).

Specialty glass consists of many segments, but the largest portion of it is laboratory and lighting glass. Optical fiber involves a series of highly sophisticated manufacturing methods. For the optical fiber, a glass core is required with a high refractive index, surrounded by glass with a lower refractive index. This problem has been solved by using several manufacturing methods, such as producing all the fiber with fused silica but doping its core with an element that increases the refractive index (Industrial Minerals, 1998d).

High-purity fused silica used by the electronics industry is typically at least 99.95% SiO_2 and has a very low expansion coefficient, high electromagnetic radiation transparency, and good insulation properties.

Slow markets have led to a difficult year for Dynasil Corp., a specialty glass manufacturer. Dynasil manufactured synthetic fused silica for the semiconductor, laser, space, and optical components industries. Sales fell by 8% in 1998 compared with those of 1997 (Glass Industry, 1998j).

The U.S. fiberglass industry consists of four major insulation manufacturers and six major textile producers. Continuous glass fiber specifications are very strict. Batch grain-size control is very important because ground silica is used as ultrafine powder. Iron, potassium, and sodium oxide content is tightly controlled. The raw mix is fused at 1,600° C and then passed through platinum bushings at 1,300° C. Mineral wool is produced from basalt and diabase (rock wool), glass (glass wool), or blast furnace slag (slag wool) (Industrial Minerals, 1998d).

The use of fiber glass in U.S.-made cars rose by 7% during 1998 and has risen by 67% since the beginning of the decade. The trend is driven by vehicle manufacturers looking for high-performance materials, particularly for engine components (Glass Industry, 1998h).

CertainTeed Corp. opened the world's largest glass fiber insulation line at its Kansas City plant. The line spanned the length of more than three football fields and was built to meet the growing U.S. demand for insulation (Glass Industry, 1998o).

Corning Inc. expanded its fiberglass production facilities in North Carolina in 1998 and planned to have a new production facility operational in 1999 (Ceramic Industry, 1998c).

Silica is used in ceramics in whole grain and ground forms. Generally, whole-grain silica is used in the ceramic body of sanitaryware (sinks, toilets, urinals, etc.), about 22% to 32%. Ground silica is used to decrease viscosity and the expansion coefficient in ceramic glazes and other ceramic applications. A typical glaze composition consists of about 25% quartz or silica. Carbo Ceramics Inc. manufactured ceramic proppants for use in the hydraulic fracturing of natural gas and oil wells. These ceramic proppants competed with natural silica sand, which is used for the same purpose (Ceramic Industry, 1998a).

Advanced ceramics, such as silicon nitride and silicon carbide, represent a growing market for silica and silica-based chemicals. Silicon carbide is manufactured by cooking silica sand or crushed quartz and oil coke at 2,400° C in an electric furnace for several days; sawdust or rice husks are added to increase porosity. Silicon carbide's thermal conductivity and expansion coefficient makes it especially useful in the refractory industry (Industrial Minerals, 1998d).

The 1988 global annual production of industrial-grade silicon carbide was on the order of 800,000 tons. Of this amount, less than 1,000 tons was used in advanced ceramics. Applications include wear parts, such as seal rings, slide bearings, shafts, and dynamic pressure, or composite bearings used in a variety of pumps. The global market for silicon nitride, which is based on powder use, is estimated to be 300,000 tons. Primary market for hybrid bearings, which is based on these materials, are machine tool spindles, aerospace components, and instruments such as dental drills, vacuum systems, and gyroscopes. Other markets for silicon nitride include engine components and cutting tools (Ceramic Industry, 1998e).

Silica is also used in plastics as an extender, filler, and reinforcer. Whole-grain and ground silica are used in filler-type applications. Ground silica is used to thicken liquid systems, to avoid plateout in polyvinyl chloride, as a thixotropic and flatting agent, and in many other filler applications. Other silica (whole grain and ground) uses include nonskid flooring, paints, putty, stucco, and other building product applications. Silica is also used in paint because it offers acid, scrubbing, and wear resistance. As segregated for this survey, consumption in 1998 of whole-grain filler was 1.89 million tons and ground silica for filler was 128,000 tons.

Cristobalite, a high-temperature silica mineral, is made from quartz by heating quartz to above 1,470° C. It consists of small octahedral crystals, which aggregate into rounded particles. The crystal structure is more open than quartz, resulting in lower specific gravity. The major market for cristobalite is in the solid mold industry, but it is also used in ceramics, grinding products, reflective coatings, refractories, and traffic paints (Paint and Coatings Industry, 1997).

Sodium silicate, produced primarily by reacting sand and soda ash in a furnace, is one of the traditional chemicals made with silica sand. One of the forces driving the increased demand for sodium silicate is the zeolite industry, which uses sodium silicate in its synthetic zeolite production.

Potassium silicate is produced in a similar fashion to sodium silicate but uses potassium carbonate or potassium hydroxide. Potassium silicate is more expensive than sodium silicate and is used primarily in welding rods.

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 does not specifically collect information for specialty silicas, consumption does affect natural silica sales. Specialty silicas and silanes (silica chemicals) included colloidal silicas, fumed silica, fused silica and quartz, organofunctional silanes, precipitated silica, silica gels, silicones, and ultra-high-purity silica. These silicas are used in a variety of industries and products, including abrasives, adhesives, beverages, catalysts, coatings, electronics, encapsulants, food, health care, optics, paper and packaging, plastics, refractories, rubber, sealants, specialty coatings, textiles, thermoplastics, wafer polishing, and water treatment.

Pyrogenic, or fumed, silica is able to form tridimensional polymers used as thixotropic agents and in silicons and silanes and is widely used as a coating agent for filler-grade calcium carbonate (Industrial Minerals, 1998e). In table 6, industrial sand and gravel that would find its way into these specialty silicas is most likely reported by the producers in the categories "Chemicals," "Silicon metal," and possibly "Glassmaking: Specialty." In 1998, silica sales for chemical production were 696,000 tons, an increase of 13.4% compared with those of 1997. Reported sales of silica gravel for silicon and ferrosilicon production decreased by about 5.3% in 1998 compared with those of 1997. The main uses for silicon metal are in the manufacture of silanes and semiconductor-grade silicon and in the production of aluminum alloys.

To meet the fast-growing demand for colloidal silica in chemical mechanical planarisation slurries used in the semiconductor industry, Clariant Corp. started production of colloidal silica in Martin, SC, in early September. The first reactor was designed to have a capacity of 6,000 tons per year. (Industrial Minerals, 1998a).

Witco Corp. has expanded the Sisterville, WV, facility of its organosilicones group. The plant manufactured difunctional silanes for the adhesives, coatings, and sealants markets. The latest addition supplemented the new 5,000-ton unit announced early in 1997 and the 2,500 tons of sulfur silane brought on in mid-1995 (Chemical Market Reporter, 1998i).

On a chemical basis, organosilanes that penetrate a concrete substrate compete with urethane and acrylic coatings, which waterproof by creating a membrane on the concrete surface. The growth rate for the global organosilanes market for concrete applications has been 10% per year. Degussa Corp. marketed two products for the concrete waterproofing market; one is a 50% organosilane and 50% water emulsion, and the other is a 100% active silane (Chemical Market Reporter, 1998d). Degussa was expanding capacity and new products for fumed and precipitated silicas; it expanded the fumed silica operations at its Mobile, AL, plant by 75% in September 1998. The company's annual growth rate was estimated to be between 5% and 7% for fumed silica (Chemical Market Reporter, 1998a).

An important and growing use for silanes is in the manufacture of silicon chips. The rapid, double-digit growth of the early and middle 1990's, however, was tempered in 1998. Along with the Asian economic crisis, which led to a slowdown in sales, other problems have exacerbated the semiconductor industry's downturn. The Japanese economy continued to struggle, and a precipitous fall in the price of memory chips added to the memory chips market's problems. Until 1995, production of memory chips was growing at an annual rate of 40%. Expecting the trend to continue, producers saturated the market, triggering a 90% drop in chip prices. Manufacturers prolonged the slump into 1998 by maintaining high levels of production to defend their market shares. Another problem plaguing the semiconductor industry has been a shift toward buying cheaper computers. The semiconductor industry's downturn began in 1997, when sales grew only 4%. Many expected the market to bounce back in 1998, but, instead, the market continued to struggle (Chemical Market Reporter, 1998c).

During 1998, Unimin cut its specialty quartz production. Initially the company announced substantial cuts in all five of its plants. By yearend, however, it announced "long-term, temporary shutdown for indefinite duration" of two of its five plants (Industrial Minerals, 1998f).

By reacting sodium silicate with hydrochloric acid, synthetic precipitated silica and silica gel are produced. Precipitated silica has been used increasingly in tires, but more so in Europe than in the United States. European consumers seem to prefer the "green" tires made with precipitated silica. Although these tires reportedly produce greater gas mileage, deficiencies in tread wear and higher costs to consumers and manufacturers account for their lack of popularity in the United States. Some new silicas, which aim to alleviate these problems, are being produced. If these problems are solved, then the "green" tire will probably become more popular in the United States. Precipitated silica is also used in battery separators and as flatting agents in coatings, mainly high-solid, low-volatile organic compound coatings.

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 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 container glass production because it is more difficult to use cullet in flint batch mixes. All types of container glass, however, are suitable for fiberglass production. The manufacturers of fiberglass insulation probably represent the largest secondary market for recycled glass containers in the United States.

Recycling of glass containers was estimated to be 34.8% of consumption in the United States in 1998, down from 35.2% in 1997. This included glass used in glascrete (cullet used in portland and asphalt concrete) and glass containers that were refilled (Glass Packaging Institute, oral commun., August 1999). The price for cullet varied on basis of region and grade [flint (clear), brown (amber), or green].

The number of North American container recycling facilities continued to grow with new plants being opened by major operators. The Chicago-based Container Recycling Alliance (CRA) processed about 500,000 tons of container cullet in 1997, about 16% more than that of 1996. The CRA used an optical color sorting system at its Chicago plant and will soon be installing a second unit at their Raleigh, NC, plant. A new beneficiation plant opened in Toronto, run by the new Canadian subsidiary of Strategic Materials, Inc., of Houston, TX. Strategic Materials' Albany, NY, plant also opened in 1998 (Glass Industry, 1998m). Additionally, the CRA will be supplying processing technology and carrying out marketing operations for a new mixed-cullet-cleaning plant in Connellsville, PA (Glass Industry, 1998e).

Container manufacturers in the United States are now using colored glass feedstock for amber and green furnaces. Changes in demand for glass containers and glass specifications mean that recycled cullet need only be separated into "clear" and "colored" fractions (Glass Industry, 1998b).

The Environmental Technology Best Practice Programme (United Kingdom) has produced a guide to improving cullet quality. The document addresses all aspects of recycling and recommends practical measures that can be taken to ensure a higher quality of cullet (Glass, 1998).

Ball-Foster Glass was reported to have reduced the level of cullet in use at its California plants in response to increasing contamination concern. Questions about the quality of the cullet are a result of a move to single-stream collection (Glass Industry, 1998f).

As the proportion of cullet used in glass production increases, so does the degree 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 acceptable iron oxide 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 silica sands are in less demand.

With the increasing value of cullet to the glassmaker, the demand for tools that improve the quality of cullet increases. As the volume of cullet increases, the level of contamination increases, and better technology is needed to separate impurities from the cullet. The first type of separators used magnetism and electrical induction to clean up the cullet. This allowed for the removal of aluminum, ferrous metals, and lead. The latest breakthroughs for separation involve a combination of laser and pneumatic technologies. These newer systems allow for the removal of ceramics, stone, porcelain (CSP), and smaller metal particles than was previously possible. Acceptable levels in processed cullet were reportedly less than 25 grams per ton for CSP and less than 5 grams per ton for metal content. This was achievable with the new technologies (Glass, 1997).

Besides the removal of impurities from cullet, sometimes the cullet must be separated on the basis of color. One system that separates by color is an optoelectronic system developed by Mogensen GmbH and Co., Wedel, Germany. The device can monitor material composition and resolution and minimize the loss of flint glass. The system can also be set for amber or green glass or CSP separation (Glass International, 1997).

With glassmakers still unable to use all the available cullet in the United States, new uses for recycled glass continue to be developed. These include recent projects to turn postconsumer glass into sand, which can be used to make tiles. Enviro Sand, Inc., was building a glass recycling plant in Scottsdale, AZ, to clean, grind, and screen glass into particles for golf course sand traps, beach replenishment, and sand blasting. About 23,000 tons per year of mixed cullet will be used by Futuristic Tile, LLC at a facility in Wood River, IL. Another anticipated use is the development of a foamed glass abrasive (Glass Industry, 1998a).

In the field of foundry sand recycling, Indianapolis Casting

Corp. has developed an automated sand- and dust-handling-mixing system. The system mixes spent molding sand and dust and produces a stable, usable, and consistent material suitable for commercial applications, including asphalt, cement manufacturing, concrete, and road fill (Rock Products, 1998b).

Silica refractories are rarely recycled because they must be crushed and ground, and the process generates silica dust. Controlling the dust according to hazardous material regulations makes the recycling prohibitively expensive.

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

Transportation.—Of the total industrial sand and gravel produced, 63% was transported by truck from the plant to the site of first sale or use, up from 62% in 1997; 34% was transported by rail, down from 36% in 1997; 2%, by waterway; and 1% was not transported. Because most of the producers did not report shipping distances or cost per ton per mile, transportation cost data are not available.

Prices.—Compared with the revised average value of 1997, the average value, free on board (f.o.b.) plant, of U.S. industrial sand and gravel increased slightly to $18.17 per ton in 1998 (table 6). The average unit values for industrial sand and industrial gravel were $18.56 and $12.41 per ton, respectively. The average price for sand ranged from $5.76 for metallurgical flux to $120.75 per ton for ground fillers. For gravel, prices ranged from $9.08 for nonmetallurgical flux to $19.63 for filtration. Producer prices reported to the USGS for silica commonly ranged from several dollars to hundreds of dollars per ton, and occasionally prices exceeded the $1,000 level. Nationally, ground sand used as fillers for rubber, paint, and putty, etc., had the highest value per metric ton ($120.75), followed by silica for swimming pool filters ($65.92), silica for well packing and cementing ($57.98), ground sand for ceramics ($49.77), ground sand for molding and core facings ($48.15), ground sand for scouring cleansers ($40.18), and ground sand for fiberglass ($40.06).

Industrial sand and gravel price changes were mixed; some markets remained level, others had small increases or decreases, and still others had large increases or decreases. Although the silica was essentially the same, this situation was possible because most markets were independent of each other and price competition was influenced by availability, regulations, health concerns, and competition from other materials.

By geographic region, the average value per ton of industrial sand and gravel was highest in the South ($19.55), followed by the Northeast ($19.07), the West ($18.90), and the Midwest ($16.47) (table 6). Prices can vary greatly for similar grades of silica at different locations in the United States. For example, the average value per ton of glass sand varied markedly—from $19.31 in the West to $12.38 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.

Foreign Trade.—On the basis of U.S. Bureau of Census data, exports of industrial sand and gravel in 1998 were about 2.5 times the amount exported in 1997, but the associated value increased by only about 10% (table 7). Most of the improvement in exports was attributable to increased shipments to Mexico, where exports increased by more than 5 times from those of 1997. For the second consecutive year, Mexico was the largest recipient of U.S. exports. Export distribution was as follows: 69% went to Mexico; 16%, Canada; 6%, Europe; 4%, Asia; and the remainder, Africa, Central America, the Middle East, Oceania, and South America. The average price, per ton, of exports dropped to $62 in 1998 from $136 in 1997. The decrease reflected increased exports of lower grade silica which averaged about $26 per ton, to Mexico. The decrease also likely reflected a decrease in frac sand exports. Excluding Mexico, all other exports averaged $142 per ton in 1998.

Census also reported that imports for consumption of industrial sand and gravel rose slightly to 44,000 tons (table 8). Silica imports vary greatly from year to year but are always rather insignificant in relation to total consumption. Australia supplied 36% of the silica imports for 1998, averaging about $55 per ton (including insurance and freight cost to the U.S. port). The total value of imports was $2.75 million, with an average of $63 per ton. Higher priced imports came from Canada, Germany, and Sweden.

World Review.—On the basis of information usually provided by foreign governments, world production of industrial sand and gravel, was estimated to be 110 million tons. The United States was the leading producer, followed by, in descending order, Paraguay, France, Austria and Germany (tied), and Spain. Most countries in the world had some production and consumption of industrial sand and gravel, which is essential to the glass and foundry industries. Because of the great variation in reporting standards, however, obtaining reliable information was difficult. In addition to the countries listed, many other countries were thought to have had some type of silica production and consumption (table 12).

In Canada, United Industrial Services Ltd., a new industrial sand company, was scheduled to open in summer 1998. The mine and plant are located near Peace River, Alberta. The mine and plant will incorporate the latest processing technology used in industrial sand plants around the world (Canada NewsWire Portfolio Email, June 9, 1998, United Industrial Services Ltd. plant manager hired, from portfolio@newswire.ca).

Current Research and Technology.— Chemical mechanical planarization (CMP) is one of the fastest growing segments of the electronic chemical and materials market. Demand for CMP slurries, which are used in chipmaking and enable complex high-performance semiconductor devices to be made more efficiently and precisely, have been increasing as the semiconductor industry moves to smaller and faster computer chips. CMP oxide slurries are made of fumed or colloidal silica suspensions stabilized with dilute potassium or ammonium hydroxides. Tagged as a mere $25 million market in 1995, the global CMP slurry market was more than $85 million in 1997, and was expected to grow in excess of 30% per year to reach $250 million by 2000 (Chemical Market Reporter, 1998g).

In corrosion-resistant concrete, alternatives to portland-cement-based systems, are time tested but mostly confined to repair and coating end uses. ZeoTech Corp. of Cherry Hill, NJ, developed a proprietary silicate-based product with structural properties of conventional concrete and durability for extreme exposure. ZeoTech blends sodium silicate solution, alkaline activator, Class F fly ash, silica-bearing aggregates, and water. The new concrete has virtually no lime or calcium, and its chemical composition is not affected by chlorides, salts, most mineral and organic acids, alkalis, or solvents (Concrete Products, 1998).

A trend towards higher furnace temperatures and through rates in conventional air-fuel fired and oxy-fuel fired furnaces has resulted in more rapid wear of many areas of the glass melters. One solution is to use a colloidal silica-based, cement-free bonding system developed by Magneco Metrel, Inc. Another related product, Met Silcast, combines this silica-bonding system with a high-purity fused silica aggregate to produce a material that is particularly suitable for crown repair and overcoating (Glass Industry, 1998c).

Nissan Chemical Industries Ltd. has developed the first spherical colloidal silica sol that forms chains like a pearl necklace. The product offers many coating and bonding benefits, including improved functions and processing relative to conventional spherical colloidal silica sold in dispersion liquid form. The material's chain structure offers high-viscosity and allows extremely large voids to form between particles after dry gel formation; this greatly improves ink absorption when used for coating inkjet paper (Chemical Market Reporter, 1998e).

Witco, Greenwich, CT, introduced a new organosilicone copolymer for haircare. Silsoft Shine can be used in water- and alcohol-based formulations to add shine and does not need to be emulsified in those that are alcohol based (Chemical Market Reporter, 1998b).

A patented process that will enable the glass industry to use substantial amounts of mixed cullet in the manufacture of glass containers and other products has been developed by G.R. Technology Inc., Haverford, PA. G.R. Technology's new process will enable glass manufacturers to use what is currently a waste product in some locations as a raw material for glass manufacture. The process also offers the possibility of freeing recycling programs from the costly process of color-sorting glass containers (Ceramic Industry, 1998d).

With the continuing closing of landfills, the United States faces the major challenge of how to handle the more than 300 million tons of hazardous waste produced every year. A potential solution to this problem lies in the form of high-temperature vitrification process originally developed in Switzerland, which can convert a wide range of waste streams into commercially viable glass-ceramic products. The final product, glass, is a rigid, noncrystalline material comprised mainly of alumina, oxides of alkali and alkaline earth elements, and silica. The organics in the waste undergo pyrolysis and become incorporated into the glass on a molecular level (Ceramic Industry, 1998h).

Following the introduction of its "large effective area fiber" for the terrestrial application earlier this year, Corning has introduced a submarine version of the fiber. With a 30% larger effective area than standard nonzero dispersion shifted fibers, the fiber is able to minimize nonlinear effects, which are the main cause of degradation in system performance (Glass Industry, 1998j).

In Japan, the Osaka National Research Institute developed a new composite material that is a combination of graphite and silicon nitride. This high-strength ceramic is extremely temperature resistant without being brittle. Osaka claimed that the composite is as strong as a typical fiber-reinforced ceramic but is considerably easier to process and costs approximately half as much to manufacture (Asian Ceramics, 1998).

Outlook.—The forecast range of total U.S. demand for industrial sand and gravel in 1999 is expected to be 27 million to 29 million tons. Probable demand is expected to be about 28 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 forecasts made by analysts and producers in the various markets.

Sales of glass sand are expected to vary from market to market. Growth that might come in some segments, such as flat and specialty glass, will be offset by reductions in sales for container glass and possibly fiberglass. The trend towards decreasing market share for container glass in the United States is expected to continue.

Global demand for packaged carbonated soft drinks is forecast to expand by 4.7% per year through 2001. For glass manufacturers, however, advances for soft drinks will trail this growth, reflecting a shifting product mix in favor of larger, multiserving containers, such as the 2-liter polyethelene terephthalate bottle. Although glass will benefit from rising soft drink demand in developing countries, such as China, loss of market share to lighter weight and shatter-resistant packaging materials will continue to limit growth opportunities in virtually every nation. The beer packaging business promises to provide good growth in the near future, but beyond 2001, the outlook is not quite so certain. Overall, demand for beer bottles is forecast to grow at an annual rate of 3% (Ceramic Industry, 1998c).

One study predicted flat glass sales in the United States, spurred on by demand from the construction (3.6% per year) and the motor vehicle (1.3% per year) markets, are expected to grow about 2.8% per year for the next several years (Ceramic Industry, 1997c).

One of the more positive, long-term trends for the global flat glass industry has been the move toward more open and fair trade, with reductions in duties and nontariff barriers. New products will also promote increased demand (Ceramic Industry, 1998b).

Schott Glass Technologies Inc. (SGT) plans to build a high-volume, top-quality glass melting and fabricating facility to supply thin sheet glass for flat panel displays. The plant will be housed in the former Topps factory situated across from SGT's main plant in Duryea, PA. Conversion of the building and plant setup were scheduled to be completed by the end of 1998, and high-volume production should be underway by early 1999 (Glass Industry, 1998g).

Demand for thermal insulation in the United States is predicted to grow at an annual rate of 2.3% through 2002, with a value of $5 billion. Fiberglass is expected to maintain its position in this market where it currently accounts for more than one half of all insulation (Glass Industry, 1998n).

Sales of optical fiber cable are expected to grow at an average annual rate of nearly 9.0% compared with 5.5% for insulated wire and cable market as a whole. The growth in optical fiber demand will be fueled by increased computer networking and the development of communications systems that are able to deliver data, video, and voice services simultaneously (Glass Industry, 1998i).

Corning began construction of its $75 million high purity-fused silica production facility outside Charleston, SC. Once it becomes operational, the plant will produce an ultrapure advanced glass for high-performance optical applications (Glass Industry, 1998d).

Total demand for glass sand is expected to grow slowly through 2000. Probable demand for glass sand in 1999 is forecast to be 11.0 million tons, with a range of 9.5 million to 12.0 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. On the basis of these factors, consumption of silica foundry sand in 1999 is expected to be 6.4 million tons, and the demand range is expected to be 6 million to 7 million tons.

Hydraulic fracturing sand sales continued to decline in 1998, decreasing by more than 16% from those of 1997. The lower sales were attributable to lower crude prices, which were reflected in lower rig activity. The Baker-Hughes' cumulative drilling rig count, reported in the weekly Oil & Gas Journal, started out about 18% higher than at the beginning of 1997, but by late May, the count had begun to decline; by midyear, the rig count was down by16% compared with that of 1997; by early fall, down by 25%; and by the end of the year, down by 37%. Oil and gas prices remained depressed in 1998, which discouraged the stimulation of marginal oilfields, a primary consumer of frac sand. As has been the case, U.S. production of oil will likely suffer as imports continue to control a higher percentage of supply. Natural gas production, however, remains the most likely source for domestic production increases and greater sand sales.

On the basis of these factors, demand for frac sand is expected to rebound slowly during 1999. Growth will be in response to improving exports and growing demand for natural gas, but it will be tempered by limited U.S. oil well activity. Probable demand for frac sand in 1999 is expected to be 1.3 million tons, with a range of 1.1 million to 1.5 million tons.

For specialty silicas, the source of the silica is usually through the chemical and silicon metal categories, which will probably see better-than-average growth, in the 2%- to 4%-per-year growth range. This positive forecast would be tempered if the specialty silicas producers use a silica source other than industrial sand and gravel. Because the process for each type of silica is highly variable and certainly not well advertised, determining the natural source and the processing method for each of the silicas or silicates is difficult.

Specialty silicas are increasingly recognized as having reinforcing properties with an average annual growth in the United States of around 4%. Expected consumption in 2003 will be 35,000 tons of fumed and precipitated fillers (Industrial Minerals, 1998c). Another forecaster also projects 4%-per-year growth for specialty silicas. They forecast fastest growth for fumed silica at 5%, precipitated and colloidal silica at 4%, and silica gel at 3.5% (Chemical Market Report, 1998h).

In 1997, PQ Corp. opened their Gurnee, IL, furnace which had a capacity of about 230,000 tons of specialty silicas. Additionally, they have an equal amount of capacity with a second furnace on standby. The second furnace will not start up for awhile, and the timing will be based on PQ's success in tapping into the emerging market for silicates as hydrogen peroxide stabilizers in pulp bleaching and paper deinking. PQ wants to replicate in the United States what it has achieved in the Canadian pulp and paper industry (Chemical Market Reporter, 1998i).

Semiconductor industry experts expect a return to historical growth in 1999, and sales should improve in all geographic regions between 1999 and 2001. Sales in the United States and Europe should grow by more than 18% per year. Japan is expected to have double-digit growth, and the rest of the Asia-Pacific region should see growth of more than 20% (Chemical Market Reporter, 1998c).

Rhodia announced an expansion of its precipitated silica unit in Chicago Heights, IL. The expansion will boost capacity by 20% to 25,000 tons. The company says the project will improve its ability to meet customers' local and global needs for precipitated silica (Chemical Market Reporter, 1998f).

For the fiberoptic market, a study predicted that the current $7.3 billion fiberoptic telecommunications equipment market will more than double to $15.4 billion by 2000 (Ceramic Industry, 1997a). Another study forecast that the North American market for single-mode fiberoptic cable will reach $2.3 billion by 2001 (Fiberoptic Products News, 1997a). Silica is used to produce not only the actual fiberoptic material, but also the equipment used to produce the fiberoptics. Promising new technologies appear likely to reduce the cost of materials and installations that would increase the use of fiberoptics, particularly in local-area-network and desktop applications. Some growth may not benefit silica, however, because of competition from other fiberoptic materials, particularly plastic optical fiber (POF). Although POF has proven itself in many short-distance applications, its use has not grown much in recent years because of manufacturing and other technical problems (Fiberoptic Products News, 1997b).

Lucent Technologies, Inc., a fiberoptics maker, planned to spend $350 million in 1998-99 to expand plants near Atlanta, GA. A small percentage of the investment will be made at other locations (Ceramic Industry, 1997b).

Although the markets and applications for silicon carbide (SiC) are diverse and growing, the world market for SiC powders was only 0.1% of the total silicon carbide tonnage sold in 1997. The potential markets for SiC powder in sintered wear parts and other advanced ceramics are large, but the commercialization of advanced SiC ceramics is being hindered by the difficulty and high cost of making components that meet the demanding industry specifications (Ceramic Industry, 1998f).

The United States is the largest producer and consumer of silica sand among the market economy countries and is self-sufficient in this commodity. Most of it is produced at premier deposits and near major markets in the Eastern United States. A significant amount of silica sand is also produced in the West and Southwest, mostly in California and Texas, respectively. 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 require a high degree of processing, the location of a silica sand deposit in relation to the market is an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supply local markets with a limited number of products.

Several factors could affect supply and demand relations for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for foundry and glass sand. These substitutes, mainly polymers and ceramics, would likely increase the demand for ground silica, which is used as a filler in plastics; for glass fibers, which are used in reinforced plastics; and for silica (chemical, whole grain, or ground), which is used to manufacture ceramics. Also, increased efforts to reduce waste and to increase recycling could hinder demand for glass sand. With advances in high-tech materials and specialty silicas, however, consumption of silica sand may increase for fiberoptics 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.

Health concerns about the use of silica as an abrasive and stricter legislative and regulatory measures concerning silica exposure could reduce demand in many silica markets. The use of silica sand in the abrasive blast industry was being questioned as a health hazard as marketers of competing materials, including garnet, olivine, and slags, pushed use of their “safer” abrasive media.

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

Quartz Crystal

Electronic-grade quartz crystal is single-crystal silica with properties that make it uniquely useful for manufacturing accurate frequency controls, timers, and filters in electronic circuits. These devices are used for a variety of electronic applications in aerospace hardware, communications equipment, computers, consumer goods (e.g., clocks, games, television receivers, and toys), and military and commercial navigational instruments. Such uses generate practically all the demand for electronic-grade quartz crystal. A lesser amount of optical-grade quartz crystal is used as lenses and windows 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 has continued. The use of quartz crystal for such applications is covered in the Gemstones Mineral Industry Surveys published annually by the USGS.

Legislation and Government Programs.—The strategic value of quartz crystal was demonstrated during World War II when it gained wide use as an essential component of military communication systems. 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, 1998, the National Defense Stockpile (NDS) contained about 107,000 kilograms of natural quartz crystal with a reported market value of about $1 million. The stockpile has 11 weight classes for natural quartz crystal ranging from 200 to more than 10,000 grams. The stockpiled crystals, however, are primarily in the larger weight classes. The larger pieces are suitable as seed crystals to produce cultured quartz crystal. In addition, many 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 used 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 disposal. On the basis of figures reported for 1997 and 1998, no natural quartz crystal was sold in 1998. Previously, only individual crystals in the NDS inventory that weighed 10 kilograms or more and could be used as seed material were sold. Brazil traditionally has been the source of such large natural crystals, but changes in mining operations have reduced its output.

Readers should refer to the Legislation and Government Programs subsection of the Industrial Sand and Gravel section of this review in which the issues of silicosis and cancer in relation to crystalline silica are discussed. Quartz crystal, a crystalline silica, is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Production.—The USGS collects production data for quartz crystal through a survey of the domestic industry. In 1998, the industry consisted of four cultured quartz crystal producers. All four growers responded to the annual survey.

The following U.S. companies produced cultured quartz crystal during 1998: 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. In early 1998, however, Motorola's quartz operations were purchased by CTS Corp., which closed the Carlisle operation. The plant manager reported that CTS, which will continue to fabricate devices using cultured quartz, will buy its quartz from foreign sources and discontinue growing quartz. The operation closed down around May 1998, and the plant was to be cleaned up and sold. P.R. Hoffman reported external sales.

The above-mentioned companies produced cultured quartz crystal by 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, high-purity natural quartz feedstock, 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 such additives 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° and 400° C; the temperature of the top portion is maintained at 5° to 50° C less, depending upon the mineralizer used. At these temperatures, the solution expands and creates an internal pressure 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 from 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. Producers, however, must avoid seed crystals with defects that could be passed 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 then 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 1998 domestic consumption data for quartz crystal through a survey of 31 U.S. operations in 11 States that fabricate quartz crystal devices. These operations represented virtually all the domestic consumption. Of the 31 operations, 21 responded to the survey. Consumption for nonrespondents was estimated on the basis of 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 aerospace, commercial, and military bandpass filter applications that require very high selectivity or for 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 automotive, consumer, and industrial products.

Cultured quartz is used almost exclusively by the crystal device industry because of the 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 applications of the natural electronic-grade material is in pressure transducers used in deep wells.

Quartz wafers 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 by 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 birefringent filters, Brewster windows and prisms, normally polarized laser beams, quartz retardation plates (especially quartz wave plates), and tuning elements in laser optics.

Prices.—The average value of as-grown cultured quartz was estimated to be about $50 per kilogram in 1998. The average value of lumbered quartz, which is as-grown quartz that has been processed by sawing and grinding, was estimated to be about $250 per kilogram. (Also note market value cited above for natural quartz crystal in the NDS.)

Foreign Trade.—The U.S. Department of Commerce (DOC), which is the major Government source of U.S. trade data, does not provide specific import or export statistics on lascas. Some lascas was imported from Brazil and Germany in 1998, according to some consumers. Imports and exports of all electronic-grade quartz crystal are listed in table 11.

World Review.—Cultured quartz crystal production is concentrated in China, Japan, Russia, and the United States, with several companies producing crystal in each country. Production is less in Belgium, Brazil, Bulgaria, France, Germany, South Africa, and the United Kingdom. Details concerning quartz operations in China, Eastern European countries, and the nations of the former Soviet Union, are unavailable. Operations in Russia, however, have significant capacity to produce synthetic quartz.

Outlook.—Because the demand for quartz crystal devices will probably continue to grow, quartz crystal production will probably remain strong well into the future. The trend towards sourcing quartz from foreign sources, could have a negative affect on domestic quartz growers. Growth of the consumer electronics market (e.g., automobiles, cellular telephones, electronic games, and personal computers), particularly in the United States, will continue to provide markets for domestic production. The growing global electronics market may require additional production capacity worldwide.

Special Silica Stone Products

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

Readers should refer to the Legislation and Government Programs subsection of the Industrial Sand and Gravel section of this review in which the issues of silicosis and cancer in relation to crystalline silica are discussed. Special silica stone, a crystalline silica, is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Production.—In response to a USGS production survey, 7 of 10 domestic firms reported that they quarried certain silica materials and manufactured silica stone products during 1998. Data for three producers was estimated. Arkansas accounted for most of the value and quantity of production reported. Plants in Arkansas manufactured files, deburring-tumbling media, oilstones, and whetstones. Elsewhere, grindstones were manufactured in Ohio, and tumbling-grinding media were produced in Wisconsin (table 10).

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, and Washita Stone has a porosity of 16% and resembles unglazed porcelain.

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

Price.—The value of crude material suitable for cutting into finished products varied from $220 to $626 per ton in 1998. The average value was $283 per ton. The average value of stone products made from crude material was $7.86 per kilogram.

Foreign Trade.—In 1998, silica stone product exports had a value of at least $5.9 million, a slight decrease compared with those of 1997. These exports were categorized as “hand sharpening or polishing stones” by the DOC. This category accounted for most of, if not all, the silica stone products exported in 1998.

In 1998, the value of imported silica stone products was at least $2.63 million, a decrease of 15% compared with that of 1997. These imports were hand-sharpening or polishing stones, which accounted for most of or all the imported silica stone products in 1998. 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 during the next several years. Most of the existing markets are well defined, and the probability of new uses is low.

Tripoli

Tripoli, broadly defined, comprises 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 micrometer 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 brown, red, or yellow depending upon the percentage of iron oxide.

Production.—In 1998, five U.S. firms were known to produce and process tripoli. American Tripoli Co. produced crude material in Ottawa County, OK, and finished material in Newton County, MO. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processed rottenstone, a decomposed fine-grained siliceous shale purchased from local suppliers. Malvern Minerals Co., Garland County, AR, produced crude and finished material and a black material from novaculite. Harbison-Walker Refractories Co., Hot Springs County, AR, produced crude and finished tripoli that is consumed in the production of refractory bricks and shapes. Unimin Specialty Minerals Inc. in Alexander County, IL, produced crude and finished material. All these firms responded to the USGS survey.

Consumption.—The 1998 USGS annual survey of producers indicates that sales of processed tripoli decreased slightly in quantity to 79,600 tons with a value of $16.9 million (tables 1 and 9).

Tripoli has unique applications as an abrasive owing 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- and 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 28 years. In 1970, nearly 70% of the processed tripoli was used as an abrasive. In 1998, slightly more than 33% of tripoli output was used as an abrasive. The remainder was used as filler and extender in enamel, caulking compounds, paint, plastic, and rubber and in brake friction products, linings, refractories, or other products.

The primary use of tripoli today 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 durability, flowability, leveling, and tint retention. In enamels, it eases application and improves sheen. The controlled grain and 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 whitings and other softer or more-reactive fillers are used.

Plastics, resins, and rubbers, each account for about 5% of the tripoli used as a filler and extender. Tripoli is used extensively in plastics for electrical uses because of its dielectric characteristics and its effects on compression and flexibility properties. Its chemical resistance, resistance to salt spray, and weatherability 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 plastic makes it valuable to the rubber and resin industries.

Readers should refer to the Legislation and Government Programs subsection of the Industrial Sand and Gravel section of this review in which the issues of silicosis and cancer in relation to crystalline silica are discussed. Tripoli is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Price.—The average reported value of all tripoli sold or used in the United States was $213 per ton in 1998. The average reported value of abrasive tripoli sold or used in the United States during 1998 was $198 per ton; the average reported value of filler tripoli sold or used domestically was $234 per ton.

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

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT U.S. SILICA STATISTICS 1/

		1994	1995	1996	1997	1998
Industrial sand and gravel: 2/						
Sold or used:						
Sand:						
Quantity	thousand metric tons	25,500	26,300	25,500	26,300	26,400
Value	thousands	$466,000	$480,000	$473,000	$485,000 r/	$491,000
Gravel:						
Quantity	thousand metric tons	1,790	1,880	2,240	2,170	1,790
Value	thousands	$22,400	$21,900	$24,100	$26,300	$22,200
Total industrial:						
Quantity	thousand metric tons	27,300	28,200	27,800	28,500	28,200
Value	thousands	$488,000	$502,000	$497,000	$511,000 r/	$513,000
Exports:						
Quantity	thousand metric tons	1,880	1,870	1,430	980	2,400
Value	thousands	$102,000	$106,000	$113,000	$134,000	$148,000
Imports for consumption:						
Quantity	thousand metric tons	24	59	7	39	44
Value	thousands	$1,790	$2,730	$1,500	$3,200	$2,750
Processed tripoli: 3/						
Quantity	metric tons	82,300	80,100	79,600	81,300	79,600
Value	thousands	$10,900	$10,500	$18,400	$16,400	$16,900
Special silica stone:						
Crude production:						
Quantity	metric tons	328	501	854	843	649
Value	thousands	$221	$270	$222	$224	$184
Sold or used:						
Quantity	metric tons	487	419	410	445	438
Value	thousands	W	W	$4,050	$2,560	$3,440
Electronic and optical-grade quartz crystals:						
Production:						
Mine	thousand kilograms	544	435	435	450	--
Cultured	do.	294	351	327	355	185

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/

	1997				1998			
Geographic region	Quantity (thousand metric tons)	Percentage of total	Value (thousands)	Percentage of total	Quantity (thousand metric tons)	Percentage of total	Value (thousands)	Percentage of total
Northeast:								
New England	218	1	$2,130	(2/)	113	(2/)	$2,440	(2/)
Middle Atlantic	2,170	8	40,300	8	2,510	10	47,500	9
Midwest:								
East North Central	10,300	36	161,000	32 r/	9,950	35	160,000	31
West North Central	1,530	5	30,100	6	1,470	5	27,800	5
South:								
South Atlantic	4,160	14	82,200	16	4,220	15	84,000	16
East South Central	1,890	7	32,500	6	2,020	7	33,900	7
West South Central	4,300 r/	15	87,700 r/	17 r/	4,260	15	87,300	17
West:								
Mountain	1,800	6	24,400	5	1,670	6	23,300	5
Pacific	2,160	8	50,300	10	2,000	7	46,100	9
Total	28,500	100	511,000 r/	100	28,200	100	513,000	100

r/ Revised.
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	1997 Quantity	1997 Value	1998 Quantity	1998 Value
Alabama	734	9,730	757	9,910
Arizona	330	3,160	307	3,290
Arkansas	W	W	W	W
California	1,920	44,900	1,740	40,400
Colorado	W	W	W	W
Florida	507	5,800	525	6,150
Georgia	520	9,330	608	10,900
Idaho	630	7,950	710	8,470
Illinois	4,610	67,900	4,580	71,100
Indiana	W	W	W	W
Iowa	W	W	W	W
Kansas	W	W	W	W
Louisiana	644	11,200	623	12,100
Maryland	W	W	W	W
Massachusetts	W	W	W	W
Michigan	2,680	30,000	2,390	25,700
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	W	W	W	W
Montana	W	W	--	--
Nebraska	W	W	W	W
Nevada	W	W	W	W
New Jersey	1,530	28,300	1,800	34,400
New York	W	W	W	W
North Carolina	1,600	26,400	1,440	24,100
North Dakota	W	W	W	W
Ohio	1,140	28,600	1,110	27,700
Oklahoma	1,380	28,200	1,380	29,600
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	770	19,300	881	20,700
Tennessee	898	16,500	999	17,100
Texas	1,800 r/	41,600 r/	1,760	38,500
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,710	33,800	1,750	34,500
Other	5,080	98,300	4,870	97,900
Total	28,500	511,000 r/	28,200	513,000

r/ Revised. 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 1998, BY SIZE OF OPERATION 1/

Size range	Number of operations	Percentage of total	Quantity (thousand metric tons)	Percentage of total
Less than 25,000	20	15	223	1
25,000 to 49,999	11	8	387	1
50,000 to 99,999	29	21	1,990	7
100,000 to 199,999	26	19	3,330	12
200,000 to 299,999	13	10	2,770	10
300,000 to 399,999	7	5	2,260	8
400,000 to 499,999	10	7	4,090	14
500,000 to 599,999	8	6	3,950	14
600,000 to 700,000	5	4	2,890	10
More than 700,000	7	5	6,330	22
Total	136	100	28,200	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 1998, BY GEOGRAPHIC REGION

	Mining operations on land					
Geographic region	Stationary	Portable	Stationary and portable	No plants or unspecified	Dredging operations	Total active operations
Northeast:						
New England	1	--	--	--	1	2
Middle Atlantic	6	--	2	--	4	12
Midwest:						
East North Central	29	--	--	1	3	33
West North Central	4	--	--	--	6	10
South:						
South Atlantic	19	--	1	2	5	27
East South Central	10	--	--	--	2	12
West South Central	9	--	--	1	10	20
West:						
Mountain	6	2	1	--	--	9
Pacific	8	1	1	--	1	11
Total	92	3	5	4	32	136

TABLE 6
INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1998, BY MAJOR END USE 1/

(Thousand metric tons and thousand dollars)

	Northeast			Midwest			South			West			U.S. total		
Major use	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/
Sand:															
Glassmaking:															
Containers	908	$16,200	$17.85	1,600	$16,800	$10.53	1,810	$27,800	$15.36	1,150	$22,500	$19.62	5,450	$83,200	$15.26
Flat (plate and window)	W	W	16.50	1,010	11,800	11.70	1,630	25,600	15.75	W	W	17.56	3,270	48,400	14.79
Specialty	W	W	24.36	W	W	15.18	252	5,810	23.00	24	711	29.95	803	16,500	20.54
Fiberglass (unground)	W	W	15.01	382	4,930	12.91	227	4,110	18.11	W	W	23.21	746	11,800	15.75
Fiberglass (ground)	--	--	--	297	11,400	38.57	453	20,100	44.42	--	--	--	619	24,800	40.06
Foundry:															
Molding and core	W	W	18.74	5,010	64,700	12.92	942	13,900	14.79	W	W	22.80	6,280	85,000	13.55
Molding and core facing (ground)	--	--	--	--	--	--	W	W	48.15	--	--	--	W	W	48.15
Refractory	--	--	--	W	W	26.65	--	--	--	W	W	22.99	58	1,540	26.63
Metallurgical:															
Silicon carbide	--	--	--	90	2,550	28.36	--	--	--	--	--	--	90	2,550	28.36
Flux for metal smelting	--	--	--	--	--	--	W	W	5.25	W	W	5.77	164	942	5.76
Abrasives:															
Blasting	65	2,290	35.32	182	4,720	25.92	1,110	27,100	24.40	144	5,260	36.65	1,500	39,400	26.23
Scouring cleansers (ground)	--	--	--	W	W	39.42	W	W	79.56	--	--	--	W	W	40.81
Sawing and sanding	W	W	20.67	--	--	--	--	--	--	--	--	--	W	W	20.67
Chemicals (ground and unground)	W	W	19.92	W	W	13.36	294	6,460	21.96	W	W	20.36	696	12,600	18.17
Fillers (ground); rubber, paints, putty, etc.	--	--	--	81	6,300	77.45	W	W	213.08	W	W	31.63	128	15,500	120.75
Whole grain fillers/building products	266	7,510	28.22	563	15,100	26.80	804	17,400	21.59	254	7,460	29.40	1,890	47,400	25.13
Ceramic (ground); pottery, brick, tile, etc.	W	W	14.33	103	5,030	48.72	65	3,510	54.05	W	W	27.02	173	8,620	49.77
Filtration:															
Water (municipal, county, local, etc.)	51	2,110	41.28	45	1,720	37.82	169	2,140	12.67	90	3,290	36.42	356	9,260	26.02
Swimming pool, other	18	1,100	62.40	10	860	86.44	25	1,520	60.28	--	--	--	53	3,470	65.92
Petroleum industry:															
Hydraulic fracturing	--	--	--	717	26,500	36.95	W	W	33.23	W	W	36.61	1,160	41,400	35.61
Well packing and cementing	--	--	--	9	770	86.69	W	W	14.58	W	W	44.10	20	1,180	57.98
Recreational:															
Golf course (greens and traps)	137	1,980	14.42	270	4,610	17.05	382	3,500	9.16	221	4,560	20.63	1,010	14,600	14.49
Baseball, volleyball, play sand, beaches	W	W	32.28	54	887	16.54	64	456	7.11	W	W	23.88	162	2,660	16.45
Traction (engine)	W	W	13.80	70	728	10.37	70	928	13.25	W	W	19.22	192	2,500	13.00
Roofing granules and fillers	38	780	20.62	W	W	4.30	W	W	23.42	W	W	15.47	151	2,810	18.65
Other (ground silica)	(3/)	(3/)	(3/)	66	954	14.44	44	9,120	208.09	(3/)	(3/)	(3/)	XX	XX	XX
Other (whole grain)	1,130	17,700	15.71	719	5,000	15.87	1,270	23,500	24.89	1,070	18,900	17.63	XX	XX	XX
Total or average	2,610	49,600	19.04	11,300	185,000	16.45	9,600	193,000	20.09	2,950	62,600	21.25	26,400	491,000	18.56
Gravel:															
Silicon, ferrosilicon	--	--	--	W	W	28.77	706	9,800	13.89	W	W	24.68	771	11,700	15.12
Filtration	W	W	26.70	74	866	11.72	W	W	52.50	--	--	--	101	1,980	19.63
Nonmetallurgical flux	--	--	--	--	--	--	--	--	--	W	W	9.08	W	W	9.08
Other uses, specified	12	316	26.30	79	1,910	24.14	193	2,540	13.10	726	6,780	9.35	918	8,580	9.78
Total or average	12	316	26.30	153	2,780	18.15	899	12,300	13.72	726	6,780	9.35	1,790	22,200	12.41
Grand total or average	2,620	50,000	19.07	11,400	188,000	16.47	10,500	205,000	19.55	3,670	69,400	18.90	28,200	513,000	18.17

W Withheld to avoid disclosing company proprietary data; for sand, included with "Other (ground silica)" or "Other (whole grain);" for gravel, included with "Other uses, specified." XX Not applicable.

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

2/ Calculated by using unrounded data.

3/ Withheld to avoid disclosing company proprietary data; included with "Other (whole grain)."

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

(Thousand metric tons and thousand dollars)

Country	1997 Quantity	1997 F.a.s. value 2/	1998 Quantity	1998 F.a.s. value 2/
North America:				
Canada	305	20,700	395	24,300
Mexico	308	11,200	1,660	42,900
Panama	4	131	16	509
Other	12 r/	652 r/	19	2,010
Total	629	32,700	2,090	69,800
South America:				
Argentina	12	1,410	4	1,080
Colombia	2	755	2	972
Peru	3	473	4	201
Venezuela	4	1,610	4	965
Other	9 r/	1,990 r/	9	869
Total	30	6,240	23	4,080
Europe:				
Belgium	5	1,240	19	1,850
Finland	19	478	6	591
France	57	2,770	68	3,220
Germany	27	24,400	10	6,530
Netherlands	14	9,280	12	7,980
Turkey	1	53	11	106
United Kingdom	4	2,150	6	2,240
Other	14 r/	2,660 r/	10	2,870
Total	141	43,000	142	25,400
Asia:				
China	1	817	10	833
Japan	76	27,900	33	26,600
Korea, Republic of	13	3,090	13	3,780
Singapore	11	4,830	21	5,430
Taiwan	18	4,370	11	4,750
Other	49 r/	5,540 r/	5	2,090
Total	168	46,600	93	43,400
Middle East and Africa	6	2,430	56	4,810
Oceania:				
Australia	5	3,360	1	372
Other	1	189	(3/)	31
Total	6	3,550	1	403
Grand total	980	134,000	2,400	148,000

r/ Revised.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Free alongside ship. 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	1997 Quantity	1997 C.i.f. value 2/	1998 Quantity	1998 C.i.f. value 2/
Australia	18	625	16	879
Canada	7	700	8	545
Germany	1	710	(3/)	343
Mexico	12	141	19	237
Sweden	2	674	1	498
Other	(3/)	345	(3/)	224
Total	39	3,200	44	2,750

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Cost, insurance, and freight. 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
PROCESSED TRIPOLI SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE 1/ 2/

Use		1994	1995	1996	1997	1998
Abrasives	metric tons	39,000	19,300	W	W	W
Value	thousands	$5,170	$2,920	W	W	W
Filler 3/	metric tons	42,800	60,700	W	W	W
Value	thousands	$5,640	$7,580	W	W	W
Total quantity	metric tons	82,300	80,100	79,600	81,300	79,600
Total value	thousands	$10,900	$10,500	$18,400	$16,400	$16,900

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, friction products, refractories, and other unspecified uses.

TABLE 10
U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1998

Company and location	Type of operation	Product
B&C, 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.
Dan's Whetstone Co., Inc.:		
Hot Springs, AR	do.	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Hall's Arkansas Oilstones, Inc., Pearcy, 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.
Pearcy, AR	Quarry	Do.
Do.	do.	Crude novaculite.

TABLE 11
SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS 1/

(Thousand kilograms and thousand dollars)

	1994	1995	1996	1997	1998
Production:					
Mine	544	435	435	450	--
Cultured	294	351	327	355	185
Exports (cultured): 2/					
Quantity	38	35	89	74	63
Value	$6,110	$10,900	$22,200	$31,100	$24,300
Imports (cultured): 2/					
Quantity	19	47	42	63	47
Value	$5,950	$10,800	$9,480	$11,700	$12,200
Apparent consumption e/	275	363	280	343	169

e/ Estimated.
1/ Data are rounded to three significant digits.
2/ Excludes mounted piezoelectric crystals.

TABLE 12
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Thousand metric tons)

Country 3/	1994	1995	1996	1997	1998 e/
Argentina	247	286	244	130 r/ p/	150
Australia e/	2,500	2,500	2,500	2,500	2,500
Austria	6,457	7,503	6,012	6,500 e/	6,000
Belgium e/	2,480	2,500	2,300	2,300	2,400
Bosnia and Herzegovina e/	50 4/	50	50	50	50
Brazil e/	2,700	2,700	2,700	2,700	2,700
Canada	1,600 e/	1,689	1,558	1,690 r/	1,700 p/
Chile e/	300	300	300	300	300
Croatia	31	341	44	98	95
Cuba e/	300	300	300	300	300
Czech Republic	1,957	1,993	2,486	2,000 e/	2,000
Denmark (sales) e/	315	50	50	50	50
Ecuador	34	26 r/	24 r/	43 r/	40
Egypt 5/	740	740	750 e/	750 e/	750
Estonia e/	25	25	25	25	25
Finland	72	30	31	30 e/	30
France e/	7,280	6,100	6,550	6,560 r/ 4/	6,500
Germany	5,680	7,315	5,503	6,000 e/	6,000
Greece	80	68	88	90 e/	80
Guatemala e/	56 r/	55 r/	47 r/	49 r/	50
Hungary 6/	512	320	325	328	325
Iceland e/	5	5	4	4 r/	4
India	1,252	1,222 r/	1,534	1,500 e/	1,400
Indonesia	588	279	300 e/	320 e/	300
Iran e/ 7/	950	1,000	1,000	1,000	1,000
Ireland e/	8	7	6	5	5
Israel	176	223	225 e/	225 e/	225
Italy e/	2,700	3,000	2,950	3,000	3,000
Jamaica	18	16	16	12	12
Japan	3,942	3,734	3,557	3,306	3,043 4/
Kenya e/	12	12	13	32 r/	32
Korea, Republic of	1,452	1,718	1,690	1,222	1,300
Latvia	76	64	50 e/	50 e/	50
Lithuania	33	46	33 e/	30 e/	30
Malaysia	231	288	269	205 e/	200
Mexico	1,360	1,293	1,425	1,564	1,600
Netherlands	25,006	23,159	24,000 e/	24,000 e/	5,000
New Caledonia e/	39	40	40	40	40
New Zealand	38	31	24	26 r/	25
Norway	891	963	960	900 e/	1,000
Pakistan e/	170	170	165	165	170
Panama e/	23	23	23	23	23
Paraguay e/	2,000	2,000 r/	10,000 r/	10,000 r/	10,000
Peru	954 r/	1,271 r/	1,672 r/	1,631 r/	1,600
Philippines e/	650 4/	800	800	800	800
Poland	1,204	1,143	137	1,300 e/	1,300
Portugal e/	5	5	5	5	5
Serbia and Montenegro	280	195	239	200 e/	200
Slovenia	210	210 e/	210	210 e/	210
South Africa	1,920	2,180	2,167	2,479	3,000
Spain	2,577	2,881	2,800 e/	2,800 e/	5,800
Sweden e/	1,500	1,500	1,500	500	500
Tanzania e/	4	--	--	--	--
Thailand e/	471	326	447	516 r/	400
Turkey	741 r/	755 r/	779 r/	1,253 r/	1,300
United Kingdom	4,038	4,200 e/	4,816	4,800 e/	4,800
United States (sold or used by producers)	27,300	28,200	27,800	28,500	28,200 4/
Venezuela	141	679	763 r/	885 r/	900
Zimbabwe 8/	131	172	96	100 e/	100
Total	117,000 r/	119,000 r/	124,000 r/	126,000 r/	110,000

See footnotes at end of table.

e/ Estimated. p/ Preliminary. r/ Revised.
1/ Table includes data available through July 2, 1999.
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, China, and Russia, among others, produce industrial sand, but current available information is not adequate to formulate estimates of production levels.
4/ Reported figure.
5/ Fiscal year beginning July 1 of that stated.
6/ For the reported volumetric quantity, see the U.S. Geological Survey Minerals Yearbook 1997, v. III.
7/ Fiscal years beginning March 21 of that stated.
8/ Includes rough and ground quartz as well as silica sand.

FIGURE 1
PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1998, BY GEOGRAPHIC DIVISION