Industrial Minerals review 2016

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Jim Norman, member SME, of Tetra Tech, is the industrial minerals annual review editor.

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ANTIMONY

by Jack Bedder, Roskill Information Services

Antimony generally occurs along with gold, lead, copper and silver. There are more than 100 antimony minerals, although the sulfide mineral stibnite is the main one.

Antimony enters the supply chain either as a result of mining (primary production) or recycling (secondary production). China has by far the largest antimony resources and is, as a result, the world's center for antimony mine production. In 2016, it accounted for more than three quarters of the global mine supply out of a world production figure of 130 kt (143,000 st), according to the U.S. Geological Survey. The biggest, and most high-grade deposits are found in southern China, with the largest mines located in Hunan, Guangxi and Yunnan provinces. Tajikistan, Russia, Australia and Bolivia are the largest mine producers outside China.

A new antimony project in Oman made progress in 2016, producing first metal in April 2016 in test facilities, and then ordered three furnaces for a 26 kt/a (28,600 stpy) antimony metal and oxide smelter that is due on stream in late 2017.

Antimony ingot production is not as widespread as is antimony mine production, owing to the high levels of pollution that are associated with antimony smelting. It is for this reason that smelting has been largely confined to China and other Asian countries, where environmental legislation is less stringent. Antimony oxide production is undertaken on four continents with China being the biggest producer. There is also a considerable amount of oxide production in Europe — which relies on imported feedstock, mostly from China.

Antimony also enters the supply chain through recycling. Lead containing antimony is produced in a number of countries, mainly in secondary lead smelters. Typically, a blast furnace charge containing used or discarded battery plates, type metal or bearing metal is reduced to lead bullion, which is refined in reverberatory furnaces and melting pots. In the main, the antimony recovered is consumed in metallurgical applications. China was the biggest secondary antimony producer in 2016, and accounted for 25 percent of world production, ahead of the United States at roughly 20 percent of the world total.

Antimony is mainly consumed in flame

retardants and lead-acid batteries. Flame retardants accounted for roughly 50 percent of consumption in 2016 with batteries representing about 25 percent. Other end uses include plastics and heat stabilizers, ceramics and glass and a variety of metallurgical applications. Demand has been sluggish since the global financial crisis, mostly because key markets failed to recover strongly from the downturn, particularly in Europe.

In flame retardants, there has been some substitution of antimony for cost and regulatory reasons in recent years.

Trade in antimony concentrates declined in the 1990s as Chinese exports, previously a major global source for producers of antimony metal and oxides, diminished in line with a policy of adding value to the product in country. During the past 10 years, trade has increased as China has sourced increasing quantities of concentrate from non domestic sources. Chinese imports in 2016 were up 6 percent compared to 2015 levels. Tajikistan, Australia and Russia are the principal exporters to China. China has also imposed export quotas on antimony ingot and alloy, and antimony oxide. In 2016, the antimony oxide quota was cut by 8 percent to 54 kt (59,500 st), while the ingot and alloy quota was cut by 36 percent compared with 2015. This had the effect of constraining supply, which was one reason behind a sharp rise in prices.

Prices saw considerable recoveries in 2016, having started the year at the lowest levels seen in recent times. Prices rose from $5,300/t ($4,800/st) in January to more than $7,000/t ($6,350/st) by the end of the year. This was mostly driven by shutdowns in China, the result of environmental inspections, reducing supply as well as the continued closure of the China-Vietnam antimony smuggling route that has limited illegal trade between the two countries.

The outlook for the plastics, construction and transportation sectors is positive. This should, in turn, eventually result in a growth in demand for antimony across all end-use sectors. Substitution of antimony in flame retardants and the increasing use of antimony-free batteries represent important long-term trends. ■

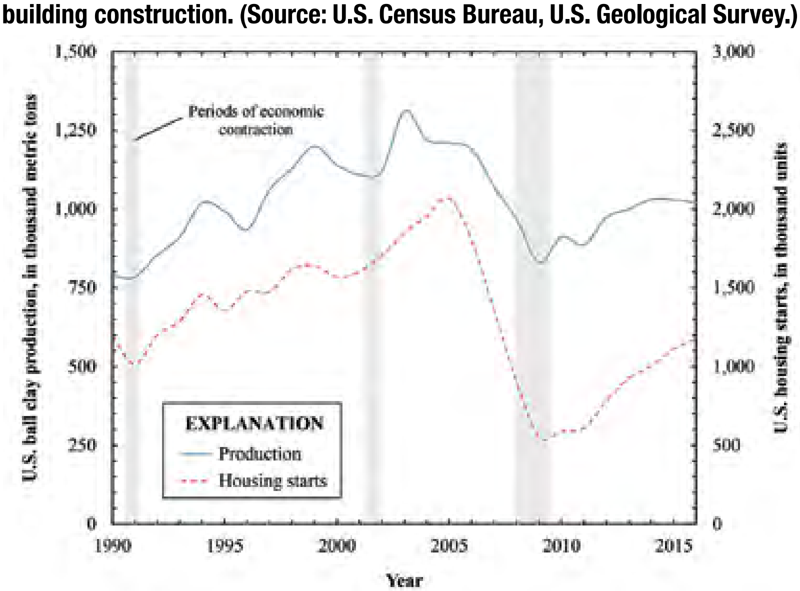
BALL CLAY

by Daniel M. Flanagan, National Minerals Information Center, U.S. Geological Survey

Since 1990, domestic ball clay production (the quantity sold or used by producers) increased from 788 kt (869,000 st) to a record high of 1.31 Mt (1.44 million st) in 2003. U.S. housing construction, a leading market for ball clay-based ceramics and sanitaryware, began to decline after 2005, which resulted in a considerable decrease in ball clay sales that continued through the economic recession of 2008–2009 (Fig. 1). After bottoming out at 831 kt (916,000 st) in 2009, ball clay output mostly increased through 2014 and has since remained relatively steady. Estimated sales in 2016 were 29 percent higher than those in 1990 and 22 percent lower than those in 2003.

Figure 1

Domestic ball clay production (sold or used by producers) and U.S. housing starts, 1990 through 2016. Ball clay production typically parallels the trend in housing starts, because the major uses of ball clay are for the manufacture of ceramic tile and sanitaryware, materials used in housing and other building construction. (Source: U.S. Census Bureau, U.S. Geological Survey.)



Four companies (H.C. Spinks Clay Co., Imerys S.A., Old Hickory Clay Co. and Unimin Corp.) mined ball clay in the United States during 2016. An estimated 1.02 Mt (1.12 million st) valued at $46 million was sold or used by domestic producers, a slight decrease from an estimated 1.03 Mt (1.14 million st) valued at $47.5 million in 2015. Tennessee was the leading producer state and accounted for nearly 60 percent of the total estimated ball clay output, followed by, in descending order of tonnage, Texas, Mississippi, Kentucky and Indiana. Production data were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration. Reliable data on global production of ball clay are not available because many countries combine ball clay production with that of other clays.

Consumption

The two principal domestic markets for U.S.

ball clay in 2016 continued to be ceramic floor and wall tile (an estimated 40 percent of U.S. and international sales combined) and sanitaryware (roughly 20 percent). Ball clay was also thought to be sold for the manufacture of bricks, electrical porcelain, fine china, pottery, refractory products, roofing granules and other types of ceramics. Although sales for fiberglass and filler, extender, and binder applications have been reported in recent years, these were likely to have been kaolin-mined or purchased by the ball clay producers.

Historical sales of domestic ball clay have strongly correlated with construction activity (Fig. 1). In 2016, housing starts increased by 6 percent to 1.17 million units from 1.11 million units in 2015, and the Tile Council of North America reported in mid-2016 that U.S. shipments of ceramic tile were on pace to rise for the seventh consecutive year. Consequently, ball clay sales may have been greater than the estimate presented above, but the available information was insufficient to confirm this inference.

Prices

Unit values for individual U.S. ball clay operations in 2016 were estimated to range from $30 to $80/t ($27 to $73/st), with an average unit value of $45/t ($41/st). Since 2000, the average unit value has remained relatively steady, ranging from a low of $42/t ($38/st) to a maximum of $46/t ($42/st). The average free-alongside-ship value for exported ball clay was $229/t ($208/st) in 2016 compared with $211/t ($191/st) in 2015, and the average customs value for imported ball clay increased to $296/t ($269/st) from $207/t ($188/st). Average unit values for exports and imports fluctuate much more than the average value of domestic production owing to the influence of small, high-value shipments.

Foreign trade

According to the U.S. Census Bureau, ball clay exports were 40.7 kt (44,800 st) valued at $9.33 million in 2016, a decrease of 16 percent from 48.3 kt (53,200 st) valued at $10.2 million in 2015. Based on import trade statistics published by Mexico's Ministry of the Economy in recent years, a sizable tonnage of ball clay exports shipped to Mexico may have been classified as kaolin. Exports of ball clay in 2016 were primarily sent to Mexico (61 percent), Japan (7 percent), and Venezuela, India and China (in descending order of quantity, 5 percent each). Ball clay imports totaled 347 t (383 st) valued at $103,000 compared with 2,200 t (2,430 st) valued at $457,000 in 2015. The majority of imports originated from the United Kingdom (87 percent) and Germany (12 percent).

Outlook

The construction industry in the United States has been on an upward trajectory during the past seven years; housing starts have risen each year since 2010, and construction spending has increased in every year since 2012. Through February 2017, the U.S. Census Bureau reported that housing starts were about 7 percent higher than at the same point during the prior year, and the International Monetary Fund projected that the U.S. economy would grow by an average of 2.4 percent in 2017 and 2018. These trends suggest that sales of ball clay will rise slightly over the next few years. Because the ball clay industry is a mature sector of the domestic economy, large changes in production and consumption are not expected to occur on a routine basis. ■

BARITE

by Andrew Scoggins, CSA Global Pty Ltd.

Barite is naturally-occurring barium sulfate ($BaSO_4$) that is utilized primarily for its high specific gravity (SG) which is 4.5 in pure form, in addition to its chemical and physical inertness, relative softness, low solubility and in certain products, white color. Natural barite products typically contain impurities such as silicate minerals (e.g. quartz or chert) which reduce the SG.

Production

Barite occurs in veins, stratiform beds and lenses in addition to residual deposits. The largest deposits currently mined are stratiform beds in China, India and the United States, though residual deposits derived from veins contribute significantly to Chinese production.

The geometry and type of barite deposit affect mining economics and processing complexity. Vein deposits have complex geometry and may often be extracted from surface or underground mines as a co-product of lead/zinc mining. Residual deposits are shallow enough to be mined opencast using dozers, excavators or front end loaders. Bedded barite deposits are more extensive, have more consistent grades and can be exploited by large-scale openpit methods.

Barite is extracted by both surface and underground mining, generally followed by simple physical processing methods, such as crushing, washing and jigging, to produce correctly sized product and to remove gangue minerals. Flotation may be used to separate barite from finely intergrown gangue minerals. Hand sorting may be used in countries with low labor costs. Acid washing may also be used to remove iron oxide stains from white barite destined for coatings markets.

World barite production is directly linked to oil and gas-well drilling activity, and annual production increased from around 5 Mt (5.5 million st) in the 1990s to a peak of approximately 9 Mt (9.9 million st) in 2012, before declining in line with the oil price to around 7 Mt (7.7 million st) in 2016 (Table 1). China accounted for around 40 percent of world production followed by India (15 percent) and Morocco (10 percent). Other significant producing countries included Iran, the United States, Turkey, Kazakhstan and Mexico.

Although China produced around 60 percent of the world's barite in 2010, by 2016 Chinese share had slipped to approximately 40 percent, due largely to the rise of Indian and Moroccan production which, by 2016, together accounted for roughly 25 percent of global output (Fig. 1). Chinese barite output peaked at around 4.5 Mt (4.9 million st) during the period 2006 to 2008 but has since declined to less than 3 Mt (3.3 million st) in 2016.

India's Andhra Pradesh Mining Development Corp. (APMDC) operates the largest single barite mine in the world at Mangampet in eastern India. The mine has about 50 Mt (55 million st) of barite reserves, following extraction of about 24 Mt (26.4 million st) since the deposit was discovered in 1954. The barite is sold by tender to local processors, in addition to being exported as lumpy ore. APMDC announced its tenders, which had been delayed for some time, in April 2016 for the sale of 600 kt (660,000 st) of SG 4.2 barite (A grade) and 200 kt (220,000 st) of SG 4.1 barite (B grade) for a period of one year. The price of barite in these tenders ranged between approximately $60 and $75/t ($54 and 68/st), for minimum quantities of 40 kt (44,000 st).

Most of the recent U.S. production in 2016 was from six mines in Nevada known as Rossi, Argenta, Slaven, Greystone, Mountain Springs and Big Ledge. The Nevada Bureau of Mines and Geology reported that 2016 production (shipped product) in Nevada declined to 209 kt (230,114 st) since peaking at 736 kt (811,000 st) in 2013 (Table 2) and is significantly less than peak production of approximately 2.3 Mt (2.5 million st) achieved in 1981.

The Nevada barite mines are operated by Halliburton, Baker Hughes, MI-SWACO and National Oilwell Varco. Most Nevada barite ore was ground at nearby company-owned grinding plants at Dunphy, Argenta, Battle Mountain and Osino.

The major drilling product suppliers, in addition to specialized mineral producers, have grinding plants around the Gulf of Mexico. These stand-alone plants processed imported crude barite that was primarily ground to API specifications for the oil and gas drilling market, although some was ground for other uses. Other mills in the Midwest and Southeast

Table 1

World mine production 2001 to 2016 (Mt).

Year	Mine production	Year	Mine production
2001	6.7	2009	6.7
2002	6.2	2010	8.0
2003	6.8	2011	8.5
2004	7.7	2012	9.2
2005	7.9	2013	8.3
2006	7.9	2014	7.5
2007	8.0	2015	7.4
2008	8.7	2016	7.1

Source: USGS.

ground barite for use as extenders, fillers and pigments, as well as producing API-grade barite for the oil and gas drilling market.

Halliburton Energy Services, together with local partner Global Chemicals Corp., has opened a 100 kt/a (110,000 stpy) capacity barite mine and processing plant at Karazhal in central Kazakhstan, about 160 km (99 miles) from Astana. The barite is being mined from an openpit at the Bestobe deposit. The plant has a capacity of 100 kt/a (110,000 stpy) of SG 4.2 barite, with the design capable of being expanded to 200 kt/a (220,000 stpy). From April 2016, 35 kt (38,600 st) of products were produced and in 2017 the company plans to increase production to 60 kt/a (66,000 stpy). Products are planned to be used locally and also exported to such countries as the Russian Federation, Azerbaijan, Turkmenistan, Denmark and Norway.

Consumption, uses and specifications

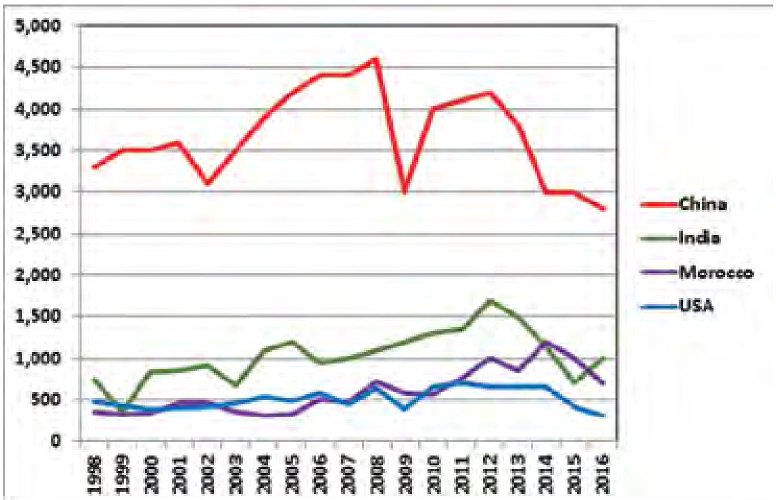
Globally, less than 80 percent of barite produced is used as a weighting agent for drilling fluids in oil and gas exploration. Mineral weighting alternatives to barite include celestite, calcium carbonate, ilmenite and synthetic hematite. Apart from calcium carbonate, none of these mineral substitutes has had a major impact on the barite drilling mud industry.

According to The Barytes Association (www.barytes.org) global barite markets are skewed. For example, 70 percent of European domestic production is for added-value manufacturing sectors where, overall, the chemical and filler industries account for half of the barite consumption. The association notes that approximately 10 percent gets used in chemical applications, e.g. electronics, TV screen, glass, ceramics and medical markets, while the remainder is used as fillers in car insulation, rubber, paint and radiation shielding.

In contrast, the United States uses more than 95 percent of its barite output for the oil drilling industry, highlighting a very general correlation between rig activity and barite consumption. The

Figure 1

Annual barite production for four leading countries (thousand metric tonnes).



American Petroleum Institute (API) introduced a new barite grade (SG 4.1) in August 2010, in addition to the long-standing 4.2 specification. The intention was not to replace the 4.2 grade, but to provide the end-user with choice as to which material to use. This change was driven in part by a shortage of SG 4.2 barite, especially from mines in Nevada. Drilling-grade barite is specified by the API and must meet certain SG, chemical and sizing requirements.

Although not an API specification, drilling companies have started to focus on heavy metal content, in particular mercury (Hg < 1 ppm) and cadmium (Cd < 3 ppm) as specified by the U.S. Environmental Protection Agency (EPA) for the Gulf of Mexico. Additional heavy metals may also be taken into account, for example, silver (Ag), arsenic (As), chromium (Cr), copper (Cu), lead (Pb), selenium (Se) and zinc (Zn), although there are no set limits for oilfield applications.

Finely ground, drilling-grade barite has been promoted by several suppliers including Halliburton and MI-SWACO. The concept is to grind (micronize) barite to a fine particle size between 0.1 and 10 microns, which is significantly finer, and in some cases denser (SG 4.35), than the conventional API-grade barite that is typically used in drilling operations. The new technology is claimed to allow for low-rheology fluids without static or dynamic barite sag in the well during drilling and completion operations, compared with normal API-grade barite which ranges up to 75 micron size.

Trade

The United States has long been a major world barite producer, primarily driven by the oil and gas drilling industry. During the first half of the 20th Century, the United States accounted for 30 to 60 percent of global production; this decreased to approximately 25 percent from the 1960s to 1980s, after which production plateaued out at around 8 percent, but by 2016 had decreased to less than 4 percent of world share.

In terms of tonnage, U.S. production reached a peak of approximately 2.3 Mt (2.5 million st) in 1980 after which it declined. It has since rebounded to about 700 kt (770,000 st) in 2013-2014, and has declined again to about 209 kt (230,000 st).

The United States relies heavily on imports of crude (lumpy) drilling grade barite which is shipped globally by sea, mainly from China and India to milling plants strategically located close to oil and gas drilling hotspots such as the Gulf States, the North Sea and the U.S. Gulf of Mexico. Milled API-grade barite is shipped to numerous destinations both from barite producing countries such as India, China, Morocco, U.S., Turkey, Kazakhstan, Mexico, Thailand and Vietnam, in addition to being shipped on from barite millers in Malaysia, Holland and the United States.

Prices

Barite prices are linked to purity and, in the case of drilling-grade barite, the SG, where SG 4.2 product commands a higher price than SG 4.1 product. There is also a variation in price according to source, as illustrated by 2014 Indian lump f.o.b. being about 20 percent higher than China.

Barite prices remained relatively steady until approximately 2006, after which they increased rapidly until around 2012 and have currently fallen back to prices similar to those seen in 2011. As an example, Indian lumpy barite SG 4.2 was around $40/t ($36/st) f.o.b. in 2006 before peaking at around $150/t ($136/st) from 2012 to 2014 and declining to around $120/t ($108/st) in late 2016.

Table 2

Nevada barite shipped, by operator, 2010 to 2016, in thousand metric tonnes.

Operator	2010	2011	2012	2013	2014	2015	2016
MI-Swaco	285	268	275	288	273	234	161
Halliburton	158	183	232	228	234	168	0
Baker Hughes	86	103	125	137	137	40	31
National Oilwell Varco	68	80	42	83	88	26	17
Total (metric tonnes)	597	634	674	736	732	468	209
Total (short tons)	658	699	743	811	807	516	230
Source: Nevada Bureau of Mines and Geology							

Outlook

Liquid fuels are expected to remain the world's largest energy source, given their importance in the transportation and industrial end-use sectors. This suggests that petroleum exploration will continue to grow and along with it barite consumption. However, the sharp downturn in oil prices since 2015 has slowed down oil and gas exploration drilling and negatively impacted barite production. This reduced production level is anticipated to continue for some time, given the reduced exploration activity due to global oil inventories. ■

BAUXITE AND ALUMINA

by E. Lee Bray, National Minerals Information Center, U.S. Geological Survey

The bankruptcies of two companies that operated alumina refineries and high costs combined with low alumina prices at another alumina refinery were the driving forces of declining bauxite imports, alumina production and alumina exports during 2016. Three primary aluminum smelters also shut down during the year, which impacted alumina consumption and imports. Sherwin Alumina Co. filed for bankruptcy protection in January citing low alumina prices and a dispute with its bauxite supplier, Noranda Aluminum Holdings Co. Bauxite sales to Sherwin were halted during the year by Noranda and then in September, Sherwin permanently shut down its 1.6-Mt/a (1.7-million stpy) refinery in Corpus Christi, TX. The labor dispute between employees, represented by the United Steelworkers Union, and Sherwin that began in October 2014, when the employees were locked out continued until the refinery was shut down. Temporary workers and management employees continued production during the lockout.

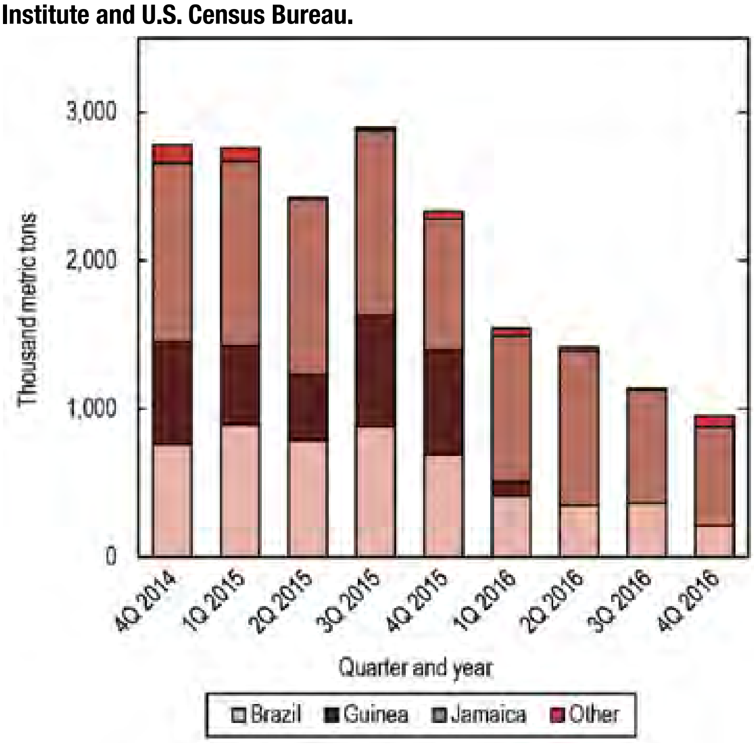
In February, Noranda filed for bankruptcy protection citing low alumina and aluminum prices and unprofitable bauxite sales to Sherwin. Noranda continued to produce alumina from its 1.2-Mt/a (1.3-million stpy) refinery in Gramercy, LA but shut down its primary aluminum smelter in New Madrid, MO in the first quarter of 2016, after a power failure occurred in January. In March, Alcoa Inc. temporarily shut down the remaining capacity at its 2.3-Mt/a (2.5-million stpy) refinery in Pt. Comfort, TX; some capacity had been shut down in November 2015. Alcoa also shut down smelters in Evansville, IN and Wenatchee, WA, in the first quarter of 2016.

Production and trade

Bauxite. The United States is 100 percent net import reliant for metallurgical-grade bauxite. Small amounts of bauxite and bauxitic clays are produced in Alabama, Arkansas and Georgia for nonmetallurgical uses. Metallurgical-grade bauxite (crude dry) imports in 2016 totaled 5 Mt (5.5 million st), 53 percent less than the quantity imported in 2015. In 2016, the leading suppliers were Jamaica (69 percent) and Brazil (27 percent). Guinea, which had supplied 2.48 Mt (2.7 million st) of bauxite in 2015 only supplied 101 kt (111,000 st) tons in 2016. Imports from Brazil declined by 2.14 Mt (2.35 million st) (62 percent) in 2016. Imports from Jamaica declined by 1.1 Mt (1.2 million st) (24 percent) in 2016 (Fig. 1). The import declines from Brazil and Guinea were attributed to the shutdown of Alcoa's Point Comfort, TX alumina refinery. Alcoa's bauxite mines in Brazil and Guinea were the principal sources of bauxite for the refinery. The decline of bauxite imports from Jamaica was attributed to the shutdown of Sherwin's refinery in Corpus Christi, TX. Sherwin's refinery had used bauxite from a mine in Jamaica owned by Noranda. In 2016, 87 kt (96,000 st) of refractory-grade calcined bauxite was imported, a 19 percent decrease compared with imports in 2015. China (61 percent) and Guyana (33 percent) were the leading sources of refractory-grade calcined bauxite imports. Imports of

Figure 1

U.S. imports for consumption of crude and dried bauxite from the fourth quarter 2014 through the fourth quarter 2016. Sources: Jamaica Bauxite Institute and U.S. Census Bureau.



nonrefractory-grade calcined bauxite in 2016 totaled 506 kt (557,000 st), 21 percent more than the quantity imported in 2015. Guyana (48 percent) and Australia (34 percent) were the leading sources.

Alumina: Domestic production of alumina in 2016 was estimated to be 2.5 Mt (2.75 million st), 41 percent less than in 2015. Imports of alumina totaled 1.14 Mt (1.25 million st) in 2016, 27 percent less than imports of alumina in 2015. Australia (33 percent), Brazil (35 percent) and Jamaica (14 percent) were the leading sources. Exports of alumina totaled 1.33 Mt (1.46 million st) in 2016, 40 percent less than exports in 2015, with Iceland (30 percent) and the United Arab Emirates (21 percent) the only destinations receiving more than 10 percent of exports.

Consumption

Total domestic consumption of bauxite (in crude dry equivalents) was estimated to be 6.48 Mt (7.14 million st) in 2016, 31 percent less than that in 2015. Of this total, approximately 5.38 Mt (5.9 million st) was used for producing alumina, 41 percent less than in the prior year. Other uses of bauxite included abrasives, cement, chemicals and refractories, as well as uses in the petroleum industry, steel production and water treatment. Total domestic consumption of alumina by the aluminum industry, which declined for the fourth consecutive year, was 1.68 Mt (1.85 million st) in 2016, 47 percent less than that in 2015 and 59 percent less than in 2012. Approximately 690 kt (760,000 st) of alumina was consumed by other industries in the United States in 2016, 9 percent less than the amount in 2015. Other uses of alumina included abrasives, cement, ceramics and chemicals.

Prices

Prices for imported and exported bauxite varied depending on the source and grade. Unit values (c.i.f.) for imported refractory-grade calcined bauxite in 2016 from the principal sources were $302/t ($273/st) from China (27 percent decrease) and $376/t ($341/st) from Guyana (4 percent decrease). In 2016, values (c.i.f.) for imported nonrefractory-grade calcined bauxite from the principal sources were $54/t ($49/st) from Australia (slight decrease) and $60/t ($54/st) from Guyana (38 percent increase). The weighted average value (c.i.f.) for crude dry bauxite from major suppliers imported in 2016 was $35/t ($32/st), 5 percent less than that in 2015. The average price (c.i.f.) for alumina imported in 2016 was $413/t ($375/st), 4 percent less than that in 2015. The average price (f.a.s.) for alumina exported from the United States increased slightly in 2016 to $390/t ($353/st) compared with the price in 2015.

Outlook

Alumina production and consumption in the United States were expected to decline again in 2017 following the shutdowns of two alumina refineries and three primary aluminum smelters during 2016. Although natural gas prices in the United States provide a cost advantage for domestic alumina refineries over refineries elsewhere, the strength of the U.S. dollar was expected to continue to offset this advantage in the export market. Primary aluminum smelters still producing in the United States were expected to maintain production levels in the near term, as aluminum prices have been increasing since midyear 2016, and smelters have long-term power supply contracts. However, relatively high power costs in the United States make it unlikely that smelters would restart capacity and therefore, alumina consumption in the United States would not likely increase in the foreseeable future. Imports of refractory-grade calcined bauxite, which are largely dependent upon steel production, are expected to remain flat. Consumption of nonrefractory-grade calcined bauxite was expected to increase in 2017 mainly as a result of increasing consumption for cement used in construction. Consumption for use in abrasives, proppants for the petroleum industry, and other products was expected to remain stable. ■

BENTONITE

by W.J. Miles, Miles Industrial Mineral Research

From a recent high of 4.8 Mt (5.3 million st) in 2014, the total bentonite market continued to decrease by about 20 percent to 3.8 Mt (4.2 million st) in 2016. While other major bentonite markets decreased in 2016, the two largest markets, clumping pet litter and drilling grade bentonite, increased to 1.44 Mt (1.58 million st) and 1.03 Mt (1.13 million st), respectively.

The new and successful fracking technology for gas and light-oil recovery from shales resulted in rapid increased use of drilling-grade bentonite. Gas production in the United States from these shales met the market demand for natural gas and reduced the price of oil to about $30 per barrel in early 2015. The price of gasoline also dropped to about $2 per gallon, significantly increasing business and family driving. Consequently, oil companies reduced further drilling for oil and gas in North America, reducing the bentonite drilling market by half to about 620 kt (683,000 st) in 2015 from 1.24 Mt (1.36 million st) in 2014. However, in 2016, this bentonite market rebounded to 1.03 Mt (1.13 million st) with renewed drilling.

Wyoming was the leading producer of swelling bentonite, followed by Utah, Montana, Texas, California, Oregon, Nevada and Colorado. Recovery from the 2008/2009 recession has not been successful for housing production and related uses in the United States. Swelling sodium bentonite dominated non-swelling calcium bentonite in North America with more than 97 percent of the bentonite market. Non-swelling calcium bentonite production occurred in Alabama, Mississippi, Arizona, California and Nevada. The major uses of non swelling calcium bentonite were in foundry sand binding, water treatment and filtering.

Outside of the United States, major producers of sodium-activated bentonite are in Greece, China, Egypt and India.

In 2015, Western Lithium USA completed its Hectatone LLC drilling-grade hectorite and organo-hectorite plant in Fernley, NV and started initial sales. In 2016, Hectatone LLC changed its name to RheoMinerals LLC.

American Colloid Co., now owned by Mineral Technologies, continues to be the leading sodium bentonite producer with about 40 percent of the market, while Bentonite Performance Minerals LLC, has about 30 percent of the U.S. bentonite market. Other major bentonite producers are M-I LLC, Black Hills Bentonite LLC, and Wyo-Ben, Inc. No new bentonite producers started in 2016. Raw material costs and truckload rates were stable in 2016.

In 2016, the clumping pet litter absorbent market was the largest swelling bentonite market at 1.44 Mt (1.58 million st). In recent years, this bentonite market has not been limited by inadequate production capacity for granular bentonite. Although the clumping pet litter market reached 1.39 Mt (1.53 million st) in 2014, it has hovered between 960 kt and 1.44 Mt (1 million and 1.58 million st) for the last 15 years. During this period, drilling-grade bentonite surpassed slumping pet litter for only three years.

The foundry sand market for bentonite has been a declining market of between 500 kt and 400 kt (550,000 and 440,000 st) for the last five years as China has been purchasing scrap iron and steel in the United States and producing finished metal products for the United States and Europe. In the second quarter 2016, the United States added an import tariff that is two to three-times the purchase price of finished iron and finished steel products. This may cause significant reduction in China imports and result in increased U.S. iron and steel production in 2017 and the following years. New product inventions have not significantly affected the markets for granular and pulverized swelling bentonite.

Iron ore pelletizing with swelling bentonite is the fourth largest market, dropping to 470 kt (518,000 st) in 2013. However, in 2014, the U.S. Geological Survey (USGS) observed that the number of bentonite producers had dropped below three, so that the USGS now reports iron ore pelletizing under miscellaneous. The new import tariff on Chinese metal goods may have the same effect on iron ore pelletizing as it will have on the foundry sand market,

In 2005, the USGS began separate classification of swelling bentonite market for civil engineering. In 2005, this market was 160 kt (176,000 st). It has now decreased to 125 kt (137,000 st) in 2015 and 2016.

For a small portion of the bentonite market, specialty markets included beverage and wine clarification and organclay products. American Colloid, Southern Clay Products SUD Chemie, and Elementis Solutions are pursuing the nano-composite market for bentonite. Elementis is currently developing new organoclay produce for oil-based drilling fluids.

The U.S. dollar exchange rate has helped swelling bentonite markets since the 2008/2009 worldwide recession; however, at the beginning of 2015, the U.S. dollar exchange rate began increasing in value versus the euro. Domestic bentonite producers reported that exports of bentonite for drilling fluids, foundry sand binder, iron ore pelletizing and other miscellaneous markets decreased to 760 kt (837,000 st) in 2016. Minor imports of bentonite came from Canada, Mexico and Greece.

Although the overall price for swelling bentonite in 2016 is not yet available, in 2015 it was $68/t ($62/st). For bagged, drilling-grade bentonite, the 2015 price ranged from $96 to $123/t ($87 to $112/st). Crude swelling bentonite for iron ore ranged from $66 to $74/t ($$60 to $67/st). Swelling bentonite for pet litter applications ranged from $50 to $60/t ($45 to $54/st). Greek bentonite from Milos, now owned by Imerys, ranged from $88 to $117/t ($80 to $106/st). ■

BISMUTH

by C.S. Anderson and K. Klochko, National Minerals Information Center, U.S. Geological Survey

In the United States, bismuth was last produced as a byproduct of lead refining in 1997. In 2015, refinery production of bismuth was estimated to be 16.4 kt (18,000 st). China was the world leading producer of refined bismuth as a byproduct of lead, fluorspar, tin and tungsten ore processing, accounting for 90 percent of the estimated world total, followed by Japan with 5 percent.

Consumption

In 2016, the estimated apparent consumption of bismuth in the United States was about 1.74 kt (1,900 st), which represented a value of approximately $17 million. About two-thirds of domestic bismuth consumption was for chemicals used in cosmetic, industrial, laboratory and pharmaceutical applications. Bismuth use in pharmaceuticals included bismuth salicylate (the active ingredient in over-the-counter stomach remedies) and other compounds used to treat burns, intestinal disorders and stomach ulcers. Bismuth also is used in the manufacture of ceramic glazes, crystalware and pearlescent pigments. Bismuth has a variety of metallurgical applications, including use as a nontoxic replacement for lead in brass, free-machining steels and solders and as an additive to enhance metallurgical quality in the foundry industry. Bismuth is also used as a triggering mechanism for fire sprinklers and in holding devices for grinding optical lenses, and bismuth-tellurium oxide alloy film paste is used in the manufacture of semiconductor devices. The Safe Drinking Water Act Amendment of 1996, which required that all new and repaired fixtures and pipes for potable water supply be lead free after August 1998, opened a wider market for bismuth as a metallurgical additive to lead-free pipe fittings, fixtures and water meters.

Imports

In 2016, all primary bismuth consumed in the United States was imported, principally from China (82 percent), followed by Mexico (7 percent), Belgium (6 percent), United Kingdom (2 percent) and others (3 percent).

Prices

According to *Metal Bulletin*, the average monthly free market price for 99.99 percent-pure bismuth began 2016 at $4.41/lb in January and remained at around $4.50/lb through June. The price fell to its lowest point in the year in the third quarter, averaging $4.30/lb in July. In the last four months of the year, average monthly bismuth prices ranged between about $4.60/lb and $4.70/lb.

Outlook

Globally, bismuth is used primarily in the industrial sectors, mostly as a metallurgical additive in steel and aluminum alloys for precision machining purposes. Emerging and growing nations drive bismuth consumption in buildings and infrastructure. Bismuth has also been used as a lead replacement for ballistics and weight applications, such as fishing weights and sinkers, because it has a similar density (9.78 g/cm^3) as lead (11.32g/cm^3), but with safer environmental effects. With more legislation restricting the use of lead in Europe and China, bismuth will be part of a growing market of lead replacements. The Nui Phao tungsten mine in Vietnam and the NICO cobalt-gold-bismuth-copper project in Canada are expected to increase both global mine and refinery production of bismuth. China's now-defunct Fanya Metal Exchange reportedly held about 19.2 kt (21,000 st) bismuth, although this quantity has not been verified by a third party and may represent a large supply of bismuth to the world market. ■

BORON (BORATES)

by R.D. Crangle Jr., National Minerals Information Center, U.S. Geological Survey

Four minerals account for 90 percent of the natural borates used by industry worldwide — the sodium borates, tincal and kernite; the calcium borate, colemanite; and the sodium-calcium borate, ulexite. Borax is a white crystalline substance, chemically known as sodium tetraborate decahydrate, found naturally as the mineral tincal. Boric acid (hydrogen borate) is a colorless, crystalline solid sold in technical, national formulary and special quality grades as granules or powder and marketed most often as anhydrous boric acid. Deposits of borates are associated with volcanic activity and arid climates, with the largest economically viable deposits in the Mojave Desert of the United States near Boron, CA, the Alpide belt in southern Asia, and the Andean belt of South America. Ore quality is typically measured as a function of its diboron trioxide (B_2O_3) equivalent content.

Production

U.S. production of boron minerals and compounds increased in 2016 from that of 2015. The actual data are withheld to avoid disclosing company proprietary data. Two companies in southern California produced boron minerals, primarily sodium borates. Rio Tinto Borax (a wholly owned subsidiary of United Kingdom-based Rio Tinto Minerals plc) extracted kernite and tincal by openpit methods at its operation in Boron, CA. The minerals were processed into boric acid or sodium borate products in a refinery adjacent to the mine and shipped by railcar or truck to North American customers or distributed internationally through the Port of Los Angeles. Specialty borates, such as agricultural, wood preservative and flame retardant products, are made at Borax's Wilmington, CA, plant. Searles Valley Minerals, Inc. (SVM) produced borax and boric acid from potassium and sodium borate brines at its Searles Lake operation near Trona, CA. The brines were refined into anhydrous, decahydrate and pentahydrous borax in SVM's Trona and Westend plants.

Consumption

Boron minerals and chemicals were principally consumed in the North Central and the Eastern United States. In 2016, the glass and ceramics industries remained the leading domestic users of boron products, consuming an estimated 80 percent of total borates consumption. Boron also was used as a component in abrasives, cleaning products and insecticides and in the production of semiconductors.

Boron was the most widely used micronutrient in agriculture, applied primarily to promote seed production. Boron fertilizers were mostly sourced from borax and colemanite owing to their high water solubility, allowing boron fertilizers to be delivered through sprays or irrigation water.

Foreign trade

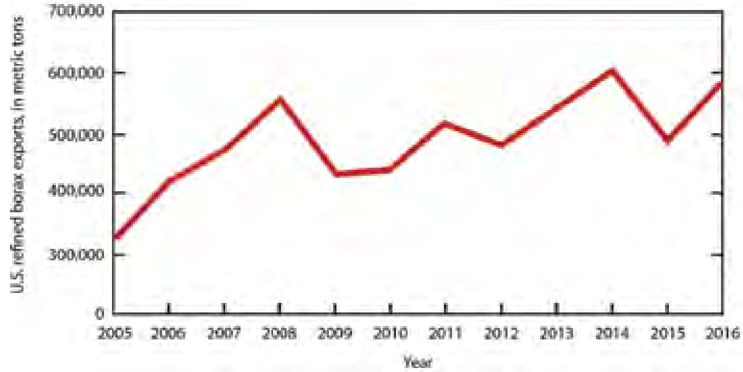
U.S. exports of refined borax were 581 kt (640,000 st) in 2016, an increase of 17 percent from 495 kt (545,000 st) in 2015. Boric acid exports of 237 kt (261,000 st) in 2016 represented an increase of 20 percent from 198 kt (218,000 st) in 2015. Since 2005, U.S. borax exports increased from 339 kt (373,000 st) to 581 kt (640,000 st) in 2016 (Fig. 1). Imports of boric acid in 2016 were 46 kt (51,000 st), about 15 percent more than those of 2015. Approximately 70 percent of imported borates originated from Turkey in 2016. The unit value for boric acid imports was $600/t ($544/st) in 2016, a 7 percent decrease from $647/t ($587/st) reported in 2015.

International

Turkey and the United States led the world in the production of borates in 2016. Chile was the leading producer of boron minerals in South America. Recent increases in borate production in Argentina, boric acid in particular, have been driven in large part by increased borate demand from the ceramics and glass industries in Asia and North America.

Figure 1

U.S. refined borax exports (HTS codes 2840190000 and 2840110000), in metric tons, 2005 through 2016.



China mines more than 100 borate deposits in 14 provinces. Boron resources in China, however, are of low quality, averaging around 8.4 percent B_2O_3, in comparison to reserves in Turkey and the United States, which have grades ranging from 26 percent to 31 percent and 25 percent to 32 percent B_2O_3, respectively. China has become more import reliant on borate products from Kazakhstan, South America, Turkey and the United States.

Outlook

Consumption of borates is expected to increase, spurred by strong demand in the agriculture, ceramic, and glass markets in Asia and South America. Demand for boron-based fertilizers was expected to rise as a result of an increase in demand for food and biofuel crops. Higher crop prices have enabled farmers to invest more capital in advanced farming techniques and higher grade fertilizers. ■

BROMINE

by E.K. Schnebele, National Minerals Information Center, U.S. Geological Survey

Two companies, Albemarle Corp. and Chemtura Corp., accounted for all U.S. production of bromine in 2016. The bromine was recovered from underground brine wells in Arkansas at a depth of about 2,400 m (7,875 ft) with concentrations of 3,000 to 5,000 parts per million bromine. Domestic production data for elemental bromine were withheld to avoid disclosing company proprietary data. However, the United States was one of the four top producers in the world, along with China, Israel and Jordan. World production of bromine in 2016, excluding the United States, was estimated to be about 391 kt (431,000 st) compared with 342 kt (377,000 st) in 2015. Global production in 2015 was lower than in recent years owing to a workers' strike in Israel, which impacted their production during the first half of 2015.

Consumption

Globally, the leading applications of bromine compounds are in the production of flame retardants, intermediates and industrial uses such as pesticides and pharmaceuticals, drilling fluids and water treatment, in descending order. Bromine compounds are also used in a variety of other applications, including chemical synthesis, control of mercury emissions from coal-fired power plants and paper manufacturing. U.S. apparent consumption of bromine in 2016 was estimated to be greater than that of 2015.

Prices

U.S. companies did not announce prices for bromine and bromine compounds in 2016. Trade publications, however, reported that U.S. bromine prices ranged from about $4,850 to $5,950/t ($4,400 to $5,400/st) during the year.

Foreign trade

In 2016, U.S. imports of bromine and bromine compounds were 71.8 kt (79,100 st), gross weight, only a slight decrease from 71.9 kt (79,200 st) in 2015. Israel was the leading source of bromine imports into the United States, accounting for 74 percent of the total quantity imported. Exports of bromine and bromine compounds decreased slightly to 29 kt (32,000 st), gross weight, compared with 30 kt (33,000 st) in 2015. Methyl bromide, a broad-spectrum pesticide, was the leading exported product, in terms of gross weight, accounting for 55 percent of exported materials in 2016. The primary recipient of exported methyl bromide in 2016 was Mexico, which accounted for 82 percent.

Outlook

Bromine and bromine compounds have been found to be highly effective at removing mercury from flue-gas emissions at coal-fired electric power plants. The U.S. Environmental Protection Agency's Mercury and Air Toxics Standards (MATS), which finalized standards for the reduction of air pollution from coal and oil-fired power plants, was confirmed in April 2016 and will likely initiate a growing market for bromine compounds as companies comply with these regulations.

The global reduction in drilling operations in 2016 led to a weakened demand for some bromine compounds that are typically used as high-density drilling fluids. Future bromine use in clear brine drilling fluids will continue to be dependent on fluctuations in the business cycle for the oil- and gas-well drilling industry.

Environmental and toxicological concerns regarding some brominated flame retardants (BFR) continued to be assessed in 2016. Questions of balancing fire safety with environmental and human health, in relation to BFRs, will likely continue to be examined in coming years. ■

CEMENT

by Brian Glackin, Quarry Management Services

Cement, more commonly known as portland cement, is an industrial mineral product rather than a specific industrial mineral. In the United States, the production of this product employs more than 14,300 workers for an annual payroll of $1 billion. The downstream consumers of this product (ready mix, concrete contractors and related industries) account for an additional 535,000 workers for a combined payroll of $25 billion (source: Portland Cement Association (PCA)). Assuming an average selling price of $110/t ($100/st), direct sales alone can account for nearly $10 billion in economic activity. Portland cement is used in modern societies for everything from ready-mix concrete in general construction, specialty cements for precast, masonry and architectural applications to geotechnical applications involving ground modification in weak soils. It is also critical to the oil and gas industry in drilling operations for the completion and or abandonment of wells. According to the PCA, there are 104 plants in the United States with a combined clinker capacity of 91 Mt (100 million st).

Primary information regarding this industry is available in monthly and annual reports published by the U.S. Geological Survey (USGS) and by press releases and limited reports released by the PCA. PCA also generates subscription reports. The remaining sources of information on the industry is through numerous trade publications that track the industry both in the United States and globally, regional news outlets reporting on specific operations and company websites/annual reports.

Portland cement is a place-value product, meaning that transportation costs can quickly limit the effective market reach of any specific manufacturing location. Plants that have historically done well have access to water and/or rail, and road transportation and are situated close to the consuming markets. In many cases, plants located many decades ago in rural areas have become engulfed in the expanding metropolitan areas they traditionally served. This is especially true along the eastern seaboard, Florida, Texas and California. Where plants have been able to continue operations in these metropolitan areas, they are often beset with challenges from the encroaching populations, resulting in higher operational costs to comply with increasing local regulation and oversight. However, in many cases these same sites benefit due to the ability to sell to their customers direct from their plant silos, eliminating shipping and storage costs associated with terminal operations. Opportunities exist in these markets for regional producers to tout the local source of these goods similar to the agricultural industries grown local campaign.

Portland cement generally is a finely ground mixture of clinker and gypsum. The clinker is a thermally processed mixture of limestone, shale, and or clay and iron. These rocks and minerals are finely ground, calcined, and then roasted to sintering temperatures where clinkering of the mineral mixture occurs. The resulting clinkers are complex silicates that are then inter ground with gypsum and additives resulting in portland cement powders. The raw materials typically represent only 10 to 20 percent of the total cost of production with the remainder coming from pyro-processing and communition requirements. Shipping logistics and terminal operations can add significant overhead on top of the cost of production depending upon distance to markets, transportation methods employed and volumes supplied.

Alternative raw materials and fuels

Limestone, argillaceous limestones, shales, sand, clays and iron ore are the traditional sources of raw materials for kiln feed. Plants are typically co-located with massive limestone deposits and where suitable shales and additives are readily sourced. Limestone continues to be the dominant source of CaO to the raw feed mix. However, a number of industrial wastes and byproducts are being sourced to supply the needed silica, alumina and iron. These include coal fly ash, spent catalyst from the petroleum industry, wastewater filter cake from food and beverage manufacturing, blast grit from metal finishing operations, to name a few. In some cases, cement operations benefit from the use of mineral byproducts from other industrial mineral processing industries.

Cement kilns typically use high-density fuels, mainly coal and petroleum coke. These fuels while efficient have inventory and grinding costs. With availability of natural gas due to shale gas development, some operations (typically older facilities) are supplementing and or replacing traditional fuels with natural gas. Additionally, for these plants, burning natural gas results in lower emissions and pollution control costs. Cement kilns continue to seek other low-cost fuel sources as well. Due to more stringent rules for sewage sludge and the ban of ocean dumping, numerous metropolitan areas have been working with cement plants to take increasing volumes of this low-density fuel. In many cases, the cement operators are paid a tipping fee to accept these materials, offsetting the added costs required to burn these fuels. Other fuel sources include plastics from numerous industries, particularly the automotive industry where many manufacturers are seeking to make their plants zero discharge. Spent fuels, solvents and hazardous wastes have long been used by the cement industry and continue to be a source of fuels for a number of plants.

Natural gypsum for many years was the primary source of gypsum to be interground with clinker. With the advent of sulfur scrubbing and the resulting production of synthetic gypsum by coal fired power stations, this new source was quickly adopted by plants. Oftentimes, this is purer than natural gypsum requiring the addition of limestone or other materials to dilute it. With many coal-fired power plants supplementing natural gas, synthetic gypsum sources may become constrained.

Statistics for 2016

In 2016, portland cement shipments experienced a slower but continued increase in demand rising to an apparent consumption of 93.3 Mt (102.3 million st) for the year representing a 2 percent increase over 2015 (USGS). Early estimates by the PCA forecasted year-over-year growth of nearly 5 percent, but slowing in construction and pre/post-election concerns tempered activity. Nearly all producers reported price strengthening although there are no good hard numbers as to average selling prices. The United States is a net importer of finished cement and clinker. Imports increased to 13.5 Mt (14.99 million st) or 19 percent over 2015 owing to a strengthening dollar and favorable shipping costs while exports fell 28 percent from 98 kt (1.08 million st) to 700 kt (780,000 st). Supply constraints in several markets where there were kiln outages due to process upgrades likely encouraged short-term importation of clinker and finished cement to make up for regional shortfalls.

While the overall consumption of cement increased, it was not uniform across the United States. Florida saw the greatest increase of cement shipments of roughly 625 kt (689,000 st), a 9.9 percent increase year over year. Georgia, North Carolina and South Carolina experienced a combined increase of 1.28 Mt (1.41 million st), a 17.6 percent increase year over year. Virginia, Colorado, Missouri, Nevada, Tennessee, Alabama and Utah experienced increased shipments between 111 kt (122,000 st) and 168 kt (185,000 st) representing individual increases of 9-12 percent for individual states. Portions of the Rust Belt, New England and the mid-south also saw shipments increase above the national average. Texas overall had decrease of shipments of 143 kt (156,000 st) due mainly to an overall decrease of demand from Southern Texas of 581 kt (640,000 st) associated with reduced oil and gas economic activity. North Dakota (-26.5 percent) and Louisiana (-28.2 percent) both experienced large downturns as well for the same reasons. The northern and southern tiers of the mountain region, mid-Atlantic and Pacific coastal states generally saw nominal growth or lost some ground.

Industry movement

2016 was marked by a number of transactions by the major players to divest operations either to suit regulatory requirements or to strengthen their financial position. In March, Cemex announced a planned sale to GCC of production assets in Odessa, TX and Lyons, CO and related businesses in Texas and New Mexico. This was scaled back to exclude the Lyons, CO assets by August for an agreed price of $306 million. The sale was completed in November. In September, Cemex announced the sale of its Fairborn, OH plant and a terminal to Eagle Materials for $400 million. The sale was concluded early in 2017.

HeidelbergCement completed its acquisition of Essroc (Italcemente) in November with the acquisition of all outstanding shares. To satisfy U.S. regulators, Heidelberg announced the sale of the Martinsburg, WV plant and eight cement terminals to Argos USA LLC in August for $660 million. Heidelberg announced the conclusion of the sale in early December. In February, Buzzi Unicem reported it had concluded the acquisition of three cement terminals in Michigan and Illinois from LafargeHolcim.

In the second half of 2015, St. Mary's Cement restarted the Dixon, IL plant after being idled in 2008 due to regulatory and financial pressures. The restart was possible after clearing regulatory hurdles imposed in 2008. The plant was reported to be at full staffing levels in June. In March of 2016, Titan America canceled plans for a greenfield cement plant in Castle Hayne, NC. This project was originally proposed in 2008.

Mine and plant investments

The majority of cement plants rely on large reserves of limestone situated at or within close proximity to their plants. However, due to the age of many of these facilities, expansion of mineral reserves are required from time to time. In 2016, several sites have had significant activity related to expansion of their mineral reserve base. Heidelberg Cement is in the process of connecting a long-held reserve in New Windsor, MD with its Union Bridge operations. Installation of an overland conveyor, opening of a new quarry and installation of new crushing stations were underway in 2016. Completion is expected in the second half of 2017. In March 2017, Capital Aggregates announced plans to open a new quarry to service its cement plant in San Antonio. Work is currently underway to receive land approvals and permits. In December, Mitsubishi Cement and San Bernardino County issued a draft environmental impact statement for a proposed expansion of its Lucerne Valley mining operations. The 153-acre expansion would allow continued operations of the adjacent Cushenberry Cement Plant for 126 years at current production capacity.

There are a number of major plant investments proposed, begun and/or completed at a number of U.S. plants in 2016. In March, GCC announced it was investing $90 million in kiln upgrades expanding cement production capacity from 1 Mt (1.1 million st) to 1.3 Mt (1.43 million st) in South Dakota. GCC estimated the project would be complete in 2018. St. Marys Cement began a $130-million upgrade of its Charlevoix plant in Michigan. The project is anticipated to be complete in the second quarter of 2018. In the fall of 2016, Buzzi Unicem USA started its previously announced line at its Maryneal, TX operations replacing three smaller kilns. In November 2016, LafargeHolcim announced the completion of a $96 million upgrade of its Hagerstown, MD operations and will increase production capacity by 200 kt (220,000 st) and result in higher efficiencies.

Environmental, regulatory and reclamation Issues

The cement industry has been under increased pressure for a number of years. EPA finalized NESHAPs mercury and HCl rules. Originally many in the industry raised concerns that this would result in several plants completely shutting down. As work has progressed, the industry has cautiously expressed that it can meet the tighter regulations due to material substitution and process changes. The industry continually faces regional and local hurdles as it upgrades plants and makes changes necessitating local permitting. Local and regional permitting often sees scrutiny by a number of national environmental groups. On the reclamation side, since many of the operations have surface mines with long lives (some exceeding 100 years), reclamation requirements are far out into the future. Many states, though not all, have reclamation bonding a part of their mineral extraction permitting. However, due to increased pressure on corporations to develop and maintain sustainability programs, most companies have reclamation plans and financial set asides for mining sites and for eventual plant closure. In metropolitan areas, the land values often exceed the value of the depleted mine resulting in the ready conversion of the site to other uses. San Antonio, TX has a number of highly developed areas that once were home to cement plants and their quarries.

Trends and outlooks

The PCA estimates growth will continue into 2017 at 3.1 percent but is guarded due to the ability of the new Trump administration to deliver on infrastructure goals with a Republican-dominated Congress that is focused on tax reductions and shrinking government. To meet future demand, the PCA estimates the current fleet of cement plants can supply 108 Mt/a (119 million stpy) of cement with potential to supply a total 150 Mt (165 million st) with imports through the current network of suppliers and terminals. Short-term spikes in demand will most likely be met by imports due to the lag time required to restart idled assets. Plant upgrades will likely be focused on eliminating the fleet of older, wet-technology plants or early precalciner technology. No greenfield plants are currently proposed in the United States with most efforts focused on increasing the longevity and capacity of existing assets. ■

CHROMIUM

by Alison Saxby of Roskill Information Services Ltd

Chromite, the only commercial source of chromium, is a spinel group mineral found in ultramafic igneous rocks. World resources are currently estimated at more than 12 Gt (13.2 billion st) of shipping-grade chromite, which is sufficient to meet forecast demand for centuries. South Africa and Zimbabwe host about 90 percent of the world's chromite reserves and resources. South African grades are lower than those mined in other countries and are smelted into charge chrome or used in chemical and foundry markets. Reserves are close to the surface and low mining costs compensate for the lower ore grades.

Roskill estimates that global chrome ore production was 28.89 Mt (31.85 million st) in 2016, almost identical to the 28.93 Mt (31.89 million st) produced in 2015. Of the total produced in 2016, metallurgical grade, used mainly to produce ferrochrome, accounted for about 96.5 percent of the global output, and the balance, around 1 Mt (1.1 million st) was used in chemical, refractory and foundry grades.

South African production accounted for just under 55 percent of global supply in 2016, and four other countries contributed more than 1 Mt (1.1 million st) of chromite. Kazakhstan (14 percent of global production) India (12 percent), Turkey (4 percent) and Finland (4 percent). Turkish production fell in 2016 from 1.45 kt (1,600 st) in 2015 to 1.1 kt (1,200 st) while Finnish production climbed from 870 kt (959,000 st) in 2015 to 1.2 kt (1,300 st) in 2016. China is the largest chrome ore importer and has limited domestic production which is estimated to have reached 280 kt (308,000 st) in 2016.

Ferrochrome has four categories, charge chrome (100 percent used for stainless steel), high carbon (HC) ferrochrome (40 percent for stainless, the rest for carbon and alloy steels), medium and low carbon (MLC) ferrochrome (around 100 percent for carbon and alloy steels).

China was the leading importer of ferrochrome for stainless steel production in 2016. Output of HC ferrochrome and charge chrome increased at 6 percent/year between 2008 and 2015 at broadly similar levels to growth in stainless steel consumption. South Africa, China and Kazakhstan are the major producers of HC ferrochrome and charge chrome, while China and Russia accounted for the majority of global MLC ferrochrome supply.

At the beginning of 2016, chrome prices hit a six-year low, which had major implications for South African ferrochrome producers. The depressed market conditions led to the closure of several ferrochrome operations, which also struggled without a stable supply of ore, forcing them to purchase on the open market. By the middle of the year, four out of the 14 South African smelters were idle, and two were partly idle. Three companies had entered business rescue in 2015.

In the second half of the year there was a dramatic recovery in the industry, and prices began to rise. By the third quarter, chrome ore prices had recovered, mostly driven by Chinese demand for South African ore for ferrochrome production, and reached levels not seen since the global economic downturn. The Chinese demand was driven by dwindling inventory levels and stimulus-linked demand for ferrochrome. The price recovery started to revive the South African sector, and there was a series of takeovers that consolidated the industry, as smaller struggling, operations were taken over by larger companies.

In addition to an improvement in Chinese ferrochrome production, where a large amount of idled ferrochrome capacity was switched back on, ferrochrome output also increased in India and Kazakhstan. This increase in production has continued into the first quarter of 2017.

Prices in 2016 rebounded sharply, with some prices recording increases of 200-400 percent over a six-month period. Markets for LC, metal and chromium chemicals remained more subdued in 2016 and prices increases were more modest. By the first quarter of 2017, 44 percent South African chrome concentrate prices averaged over US$400/t ($360/st) CIF China, according to *Metal Bulletin*, while UG_2 chrome ore (42 percent) averaged just over US$380/t ($345/st). However, going forward, it is predicted that there will be an oversupply of ferrochrome in 2017 if production continues at current levels. This will likely provide a brake on chrome ore prices and modest declines are expected in the second half of the year. ■

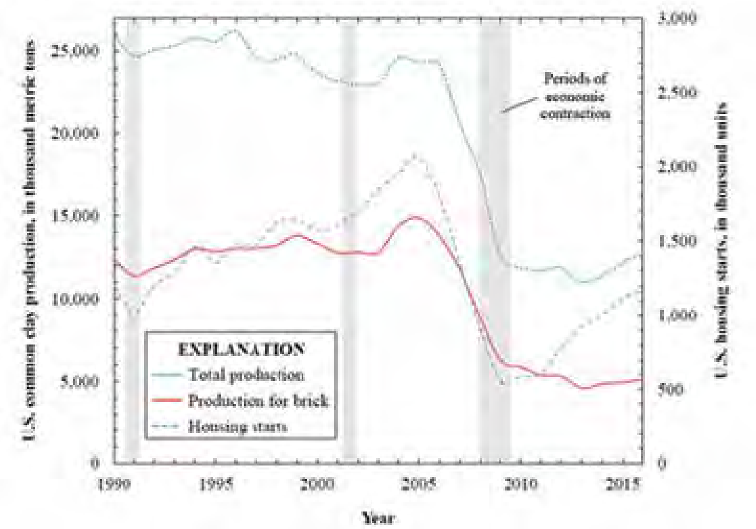
COMMON CLAY AND SHALE

by Daniel M. Flanagan, National Minerals Information Center, U.S. Geological Survey

U.S. production of common clay and shale (the quantity sold or used by producers) has trended downward since 1990, when output was 25.9 Mt (28.5 million st). Domestic housing construction, a leading market for common clay-based products, began to decline after 2005. This resulted in a considerable decrease in sales of common clay and shale that continued through the 2008–2009 economic recession (Fig. 1). After bottoming out at 11 Mt (12.1 million st) in 2013, common clay and shale production increased in each of the next three years. Estimated sales in 2016 represented about 50 percent of those in 1990 and

Figure 1

U.S. housing starts and domestic production (sold or used by producers) of total common clay and common clay used in brick, 1990 through 2016. Common clay production typically parallels the trend in housing starts because the major uses of common clay are for the manufacture of brick, cement and lightweight aggregate, materials used in housing and other building construction. (Source: U.S. Census Bureau, U.S. Geological Survey).



approximately 60 percent of those in 2007, prior to the recession. Common clay and shale have accounted for an annual average of roughly 60 percent of U.S. production of all clay types since 1940 and represented an estimated 50 percent of the total output in 2016.

Nearly 100 companies produced common clay and shale for manufacturing products in 38 states during 2016. Operations that mined common clay for uses such as construction fill, landfill caps and landscaping but did not operate mills or plants, were not included in the data. These companies operated in most, if not all, states. The quantity of common clay and shale sold or used increased by 5 percent to an estimated 12.8 Mt (14.1 million st) valued at $170 million from 12.2 Mt (13.4 million st) valued at $164 million in 2015. The 10 leading producer states were, in descending order of tonnage, Texas, Alabama, Oklahoma, North Carolina, Oregon, Ohio, New York, California, Indiana and Arkansas. These states collectively accounted for about 70 percent of domestic common clay sales. Preliminary production data for 2016 were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration. Reliable global production data are not available because many countries do not report output of common clay and shale.

Consumption

Brick manufacture remained the leading end use for U.S. common clay and shale in 2016, accounting for more than 40 percent of sales. Sales for brick increased for the third consecutive year, corresponding to growth in the domestic construction industry, where housing starts increased by 6 percent relative to those in 2015. Prior to 2014, the use of common clay in brick had not increased since 2005 despite several successive years of rising housing starts (Fig. 1). According to one major U.S. producer, brick demand has been hindered by shifts to the use of alternative materials, construction of multifamily dwellings, and a focus on entry-level housing. The other primary markets for common clay and shale in 2016 were for the production of cement and lightweight aggregate. Combined sales for these applications accounted for more than 50 percent of total sales and increased slightly compared with those in 2015, following the trend in domestic shipments of cement. Other uses included ceramic floor and wall tile; fillers, extenders, and binders; miscellaneous ceramics; refractory products and roofing granules.

Prices

In 2016, unit values for individual common clay and shale operations in the United States varied from less than $1 to $90/t ($0.9 to $82/st), and the average unit value was an estimated $13/t ($12/st), unchanged from that in 2015. Estimated average unit values of common clay and shale used to produce specific products were as follows: building brick, $5/t ($4.50/st); lightweight aggregate, $37/t ($34/st); and cement, about $4.50/t ($4/st). Prices for common clay and shale should be viewed with caution because most producers do not sell their clay directly but use it to manufacture products.

Foreign trade

International trade of common clay and shale is limited because most countries have more than adequate reserves and transportation costs relative to the clay value are prohibitive. The U.S. Census Bureau reports exports of clay under Harmonized Tariff Schedule 2508.40.0150 (clays not elsewhere specified or included) as 256 kt (282,000 st) valued at $72.6 million in 2016, down from 268 kt (295,000 st) valued at $73.6 million in 2015. Imports under this classification totaled 11.3 kt (12,500 st) valued at $5.46 million in 2016 and 9.32 kt (10,300 st) valued at $5.30 million in 2015. This trade category, however, includes significant tonnages of other clay types in addition to common clay.

Outlook

The construction industry in the United States has been on an upward trajectory during the past seven years; housing starts have risen each year since 2010, and construction spending has increased in every year since 2012. Through February 2017, the U.S. Census Bureau reported that housing starts were about 7 percent higher than at the same point in 2016, and the International Monetary Fund projected that the U.S. economy would grow by an average of 2.4 percent in 2017 and 2018. These trends suggest that sales of common clay and shale will rise slightly over the next few years. ■

CONSTRUCTION AGGREGATES

by Mark J. Zdunczyk, Consulting geologist

Construction aggregates is a general term to define crushed stone, sand gravel, slag or other material such as recycled asphalt pavement (RAP) or recycled concrete used in portland cement concrete (PCC), bituminous concrete (asphalt), road base, railroad ballast, concrete block and filter stone or sand, to name a few. Most construction aggregates are consumed by the concrete and asphalt industry.

Crushed stone is mined from many rock types. The U.S. Geological Survey (USGS) lists the types of rock sold for construction aggregates as limestone, dolomite, marble, calcareous marl, shell, granite, traprock (basalt, diorite) sandstone/quartzite, slate, volcanic cinder, scoria and miscellaneous materials. Some rock types and materials such as shell, slate, calcareous marl, volcanic cinder and scoria generally cannot meet the specifications required in most states to be used in PCC and asphalt. Volcanic cinder and scoria may be used as lightweight aggregate sources or in concrete blocks, if the material meets the specifications set forth by that industry.

In 2016, the USGS estimates that 1.48 Gt (1.63 billion st) of crushed stone valued at more than $16.2 billion was produced by 1,430 companies operating 3,700 quarries, 82 underground mines and 187 sales and distribution yards in 50 states. This does not account for all the so called "ma and pa" mines that mine rock and sand and gravel for low-grade construction materials. These mines are small, production intermittent and generally do not report their activities to the USGS.

Aggregate mining has always been the largest mining sector in the United States as per number of mines and volume. The USGS reports that the leading states in production are: Texas, Pennsylvania, Florida, Missouri, Ohio, North Carolina, Georgia, Indiana, Illinois and New York. In 2015, the first five states in descending order were the same as 2016 except Missouri and Florida reversed order.

Construction aggregates must meet various state, federal, industry and sometimes local specifications to be used in PCC, asphalt, and other uses that require quality crushed stone or sand and gravel. Much of the physical testing required is set forth by the American Society for Testing and Materials and the American Association of State Highway Officials which many states use as their requirements. The Federal Aviation Administration and the Army Corp of Engineers have their own specifications for airport runways and taxiways, jetty or armor stone. In addition, railroads have their specifications for ballast stone and traction sand. Some state, federal and local regulators require the Los Angeles Abrasion (LA) test. The LA method covers the procedure for testing coarse aggregate for resistance to degradation. The five-cycle magnesium and sodium sulfate soundness tests determine an aggregate's resistance to disintegration by weathering particularly freezing and thawing cycles. The LA and soundness tests are suggested to be performed on coarse aggregate to determine suitability of the rock to meet specification before the many other tests that are needed. Those tests are: deleterious material, particle size and shape, chemical and mineral contaminants, especially iron sulfide minerals and asbestiform and non asbestiform minerals, specific gravity and absorption, skid resistance (friction), hardness and freeze-thaw, alkali silica or carbonate reactivity, and petrographic analysis. Skid resistant or friction aggregate generally requires all rock that passes physical specifications set forth by the particular agency to be non carbonate. Therefore, limestone or dolomite cannot be used on the top course of most roads. Some states have a specification on the residue left after a certain size carbonate aggregate is placed in concentrated hydrochloric acid and dissolved. The residue left, if significant enough, may be used on the top course of less traveled roads.

States require different tests or limits on some tests to accommodate the rock or sand and gravel in their area. For example, Texas Department of Transportation (TXDOT) allows the individual TXDOT regional office to decide whether to require a five-cycle sodium sulfate test or a five-cycle magnesium sulfate test on course aggregate. In Oregon, a dimethyl sulfoxide (DSMO) test is used and, in the New York State Department of Transportation Bureau of Materials a 10-cycle magnesium sulfate test is required on coarse aggregates. Other states have different tests and different loss limits depending on the quality rock or sand and gravel in the area.

Construction aggregates markets can range from low grade material such as fill, road base and miscellaneous products to washed and sized aggregate sold to the ready-mix concrete and asphalt producers. The market area is generally within trucking distances as trucks transport about 85 percent of aggregate in the United States. Rail, barge or ship transport amounts to about 15 percent. As an industry rule of thumb, trucks can generally travel 56 to 64 km (35 to 40 miles) before transportation costs increase significantly. These costs depend on many factors such as road conditions, traffic, tolls, bridges, back hauls and weight laws. For example, relatively straight routes with limited traffic signals can allow trucks to carry material much farther than 64 km (40 miles) at low rates. Conversely, in areas near New York City, Atlanta, Dallas/Fort Worth, Los Angeles and other major cities, trucks are slowed by traffic congestion. In these cases, many of the trucks charge an hourly rate. Generally, all shipments or delivery are based on a ton-mile basis. These charges vary from state to state or region to region in the United States. Most aggregate produces do not own their own trucks for delivery, many use contract trucking companies.

Rail rates are less than trucking rates, but rail has limited areas of service, and the producer using rail generally owns or leases a sliding on the production end and a distribution yard on the delivery end. Extra costs for rail include storage, loading and unloading. The additional handling incurs more costs. Those producers who have rail access generally have the ballast stone market.

Barges and ships are used on the east and west coasts, Mississippi, Missouri, Ohio and Columbia Rivers, inter-coastal waterways and the Great Lakes. Water aggregate shipments generally are less costly than rail, but the same extra costs are added at the dock or wharf such as demurrage or the time it takes to unload or load the material.

Construction aggregates are sold free-on-board (f.o.b) quarry or sand and gravel pit. f.o.b. prices are listed at the scale house and provided by sales people. The f.o.b. prices do not reflect the price to the contractor, bid work by the producer or those companies that buy in large volumes. In addition, when producers are vertically integrated, their price from their quarry for crushed stone or sand and gravel to their asphalt plant or concrete batch plant may be the exact f.o.b. price or lower depending on which business unit or product needs the cost increase or decrease. Where aggregate is needed, f.o.b. prices are generally higher than in areas where aggregate is abundant. For example, in Charleston, SC, f.o.b. prices for crushed aggregate of any type is generally higher than in Anderson, SC because quality aggregate must be railed or shipped from the Bahamas or Nova Scotia, Canada. In many major cities, f.o.b. prices are generally higher than other urban areas.

The marketability of the product depends on the results of some or all of the physical tests. However, there are many producers whose aggregates do not meet certain specifications but are sold for low-grade construction products or non-state specification stone. Many producers in the United States sell more non-specification aggregate by volume than approved state aggregate. Generally, it is important to be a state-approved source for crushed stone or sand and gravel aggregate.

Sand and gravel as construction aggregate are used for many of the same purposes as crushed stone. There are some differences that are mostly geographic in nature. In the aggregate industry, geography plays an important role between the two aggregate sources. Where there are large deposits of sand and gravel, such as the large alluvial fans of California or the glacial deposits in the northeast or north central states, sand and crushed gravel is widely used. Where there are large deposits of rock, crushed stone is generally used such as the Atlanta, GA area. There are two exceptions, natural sand is preferred over manufactured or stone sand by most ready-mix concrete producers and crushed stone is preferred over crushed gravel for the same use. Crushed stone is also preferred in asphalt. In both PCC and asphalt, crushed stone is more uniform, generally having one rock type while crushed gravel may contain several lithologies or rock types. In ready-mix concrete and asphalt, each lithology may absorb more water or react differently to the cement additives or liquid asphalt. Natural sand use for PCC is difficult to find as it requires a specific gradation. Much of the natural sand found today is too fine-grained to meet the size specifications.

In 2016, the USGS estimates 1 Gt (1.1 billion st) of sand and gravel were produced in the United States. The five leading states were Texas, California, Michigan, Minnesota and Utah. In 2015 Utah did not make the top five. Texas and California were common to both of the top five statistics. The majority of sand and gravel production in 2016 went to concrete aggregates such as ready-mix concrete. These leading states have an abundance of mines in the alluvial fans, colluvium, river deposits, and glacial deposits. Most, if not all, of the specifications required by states for crushed stone are the same for sand and gravel aggregates. States do have exceptions and some have tests which may be much different than other states.

Recycling has increased in recent years. Recycled asphalt pavement (RAP) and recycled concrete are generally used for base materials as they do not meet many state specifications for state approved PCC or asphalt aggregate. Although recycling is very green, realistically it hasn't quite reached the market place. The USGS reports that recycling is still a small percentage of aggregate consumption. As for other substitutes, such as slag, there are quality issues that prevent major use in the industry especially for steel slag. Other restrictions are the availability of the material and environmental concerns. Asphalt shingles are recycled at asphalt plants and used as fillers and liquid asphalt after heating and extraction. Sand in asphalt is used as a filler and, in years past, comprised most of the filler. The specifications for asphalt sand were liberal and, in most cases, did not need to be washed. Many of these asphalt producers have stockpiles of RAP on their sites and now are blending washed concrete grade sand with RAP. RAP has an abundance of fine material and therefore requires washed concrete sand so that the sand has less fines. In some areas of the country, concrete sand producers are providing washed sand to both ready-mix concrete and asphalt producers.

Construction aggregates have many issues facing the industry. Since a number of rock quarries and sand and gravelpits need to be near urban areas in order to get their produce cheaply to the market, the general public is exposed to their operations more than any other mining industry. The industry has come a long way in mitigating many environmental concerns of the local citizens. Today, all of the major companies and most of the other aggregate producing companies have environmental managers who handle all environmental issues. Because about 85 percent of aggregate production is transported by truck, truck traffic remains a concern to local citizens and is difficult to mitigate. Dust, noise, blasting, wetlands issues, and safety issues have through the years been widely mitigated in most operations. Still, opposition from not-in-my-backyard (NIMBY) citizens costs the industry undue expenses in the new or expansion quarry or sand and gravel pit permitting process. Therefore, the industry seems to prefer acquisitions rather than greenfield sites.

Acquisitions continued in 2016 by those companies that needed to increase their market share. In 2016 as 2015, US Concrete Inc. Summit Materials, Martin Marietta Materials Inc., Rogers Group Inc., Vulcan Materials and Blue Grass Materials acquired various size operations or potential aggregate sources throughout the country or region. Several smaller, relatively unknown producers, have also acquired properties or small operations throughout 2016. Some of these acquisitions are reported others are not.

The U.S. Mine Safety and Health Administration (MSHA) continued its inspections on the industry. Each quarry and sand and gravel operation is different and one regulation may not fit all. Most large aggregate operations have health and safety managers on staff to help comply with MSHA regulations. ■

DIATOMITE

by R.D. Crangle, Jr., National Minerals Information Center, U.S. Geological Survey

The United States continues to be the world's leading producer and consumer of diatomite. Production of diatomite in the United States during 2016 was estimated to be 850 kt (936,000 st), slightly more than that in 2015. Six companies operated 11 mines and nine processing facilities in California, Nevada, Oregon and Washington. U.S. diatomite exports were about 66 kt (73,000 st). Imports were much lower at approximately 8 kt (8,800 st). Total world production of diatomite was approximately 2.7 Mt (3 million st) in 2016. Following the United States in diatomite production; other significant producers in 2016 were China (420 kt or 463,000 st), Peru (150 kt or 165,000 st), Japan (100 kt or 110,000 st), Mexico (80 kt or 88,000 st) and Turkey (60 kt or 66,000 st). World resources of crude diatomite appear to be adequate for the foreseeable future. However, transportation costs may encourage development of sources of material closer to markets.

Diatomite is a chalk-like, soft, friable, very-fine-grained, siliceous sedimentary rock. Typically light in color (white if pure, commonly buff to gray in situ), diatomite is also very finely porous, very low in density and essentially chemically inert. Diatomaceous earth (DE) is a common alternate name, but the term is more appropriate for unconsolidated or less lithified rock of the same origin.

Diatomite deposits accumulate in oceans or fresh waters from the cell walls of diatoms, composed of amorphous hydrous silica. Diatoms are microscopic, single-celled organisms, often appearing as colonial aquatic plants (algae). Diatom cells contain an elaborate internal siliceous skeleton. More than 10,000 living diatom species have been identified, in addition to another 10,000 known diatom fossil forms.

Prices

The unit value of diatomite varied widely by end use in 2016. Diatomite used as an absorbent was priced at \$10/t (\$9.07/st) but specialty-grade diatomite, used in art supplies, cosmetics or biomedical applications, was priced as high as \$10,000/t (\$9,000/st). Filter-grade diatomite had an average unit value of \$416/t (\$377/st). Since 2005, the average unit value of diatomite has varied from \$220/t (\$200/st) to \$298/t (\$270/st) (Fig. 1).

Uses

The internal structure and inert chemical composition of diatomite make it an excellent raw material for filtration, absorbent and filler applications (Fig. 2). Filtration, especially the purification of beer, liquors and wine, and the cleansing of greases and oils continued to be the largest end use for diatomite. Other applications included the removal of microbial

Figure 1

Average value of diatomite expressed in dollars per metric ton, 2005 to 2016 (USGS).

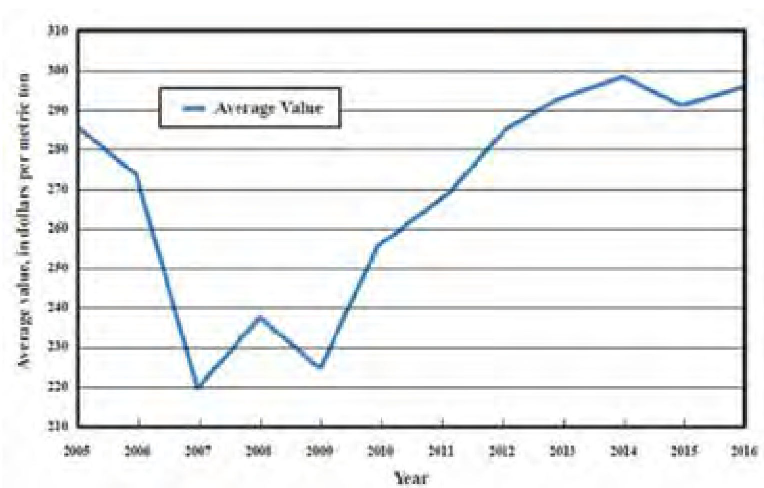
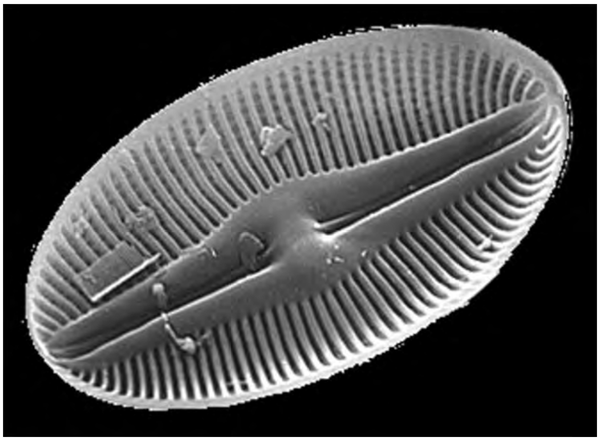


Figure 2

Scanning electron micrograph of *Diploneis puella*, a diatom approximately 20 microns in length. One micron is 1 millionth of a meter. Note the very fine web-like openings, less than 1 micron in thickness, which create an ideal filter media (courtesy USGS, http://gec.cr.usgs.gov/archive/lacs/diatom.htm).



contaminants, such as bacteria, protozoa and viruses, from public water systems. The use of diatomite as a filler, which serves to displace higher-cost raw materials and in pharmaceutical applications, including the filtration of human blood plasma, continues to increase, as has its use as an insecticide base and in cement and concrete pozzolan. In 2016, diatomite-derived products included filter aids (60 percent of diatomite consumption), lightweight aggregates (25 percent), fillers (10 percent), absorbents (5 percent) and other minor uses, including specialized pharmaceutical and biomedical applications (less than 1 percent).

Processing

Diatomite deposits are usually mined as openpit operations. If necessary, the mined crude ore is dried and crushed. Dried diatomite is collected in cyclones and fed through air separators to remove coarse material and impurities. Calcination and flux calcination are used to thermally volatize organic material and oxidize iron. Calcination also is used to increase diatomite hardness, specific gravity and refractive index. The fusing of small diatomite particles into clusters can also be accomplished through calcination, which results in increased pore size and volume. Diatomite products are sold as various grades of calcined powders.

Substitutes

Many materials can be substituted for diatomite, especially for lightweight aggregate purposes, such as expanded perlite and silica sand. Synthetic filters, including ceramic, polymeric, or carbon membrane and cellulose fibers offer competition as filter media. Alternate filler materials include clay, perlite, talc, vermiculite, ground limestone, mica and silica sand. For thermal insulation purposes, materials such as specialty brick, various clays, mineral wool, expanded perlite and exfoliated vermiculite may be used. Many alternatives exist for diatomite as a pozzolan, but its use as an ingredient of portland cement has increased in recent years. The encroachment of natural and synthetic substitute materials into diatomite markets has not been significant. ■

DIMENSION STONE

by Thomas P. Dolley, National Minerals Information Center, U.S. Geological Survey

Dimension stone can be defined as natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size (width, length and thickness) and shape for architectural or engineering purposes. Color, grain texture and pattern and surface finish of the stone are also normal requirements. Durability (essentially based on mineral composition, hardness and past performance), strength, and the ability of the stone to take a polish are other important selection criteria. Although a variety of igneous, metamorphic and sedimentary rocks are used as dimension stone, the principal rock types are granite, limestone, marble, sandstone and slate.

Production

Approximately 2.46 Mt (2.7 million st) of dimension stone, valued at $468 million, was produced domestically in 2016. Dimension stone was produced by 236 companies operating 276 quarries in 34 states. Leading producer states, in descending order by tonnage, were Texas, Indiana, Massachusetts, Wisconsin and Georgia. These five states accounted for 64 percent of the tonnage and contributed about 60 percent of the value of domestic production. Approximately 43 percent, by tonnage, of dimension stone sold or used was limestone, followed by granite (22 percent), sandstone (18 percent), miscellaneous stone (13 percent) and marble and slate (2 percent each). By value, the leading sales or uses were for limestone (36 percent), followed by granite (28 percent), miscellaneous stone (15 percent), sandstone (13 percent), and marble and slate (4 percent each). Rough block represented 59 percent of the tonnage and 48 percent of the value of all the dimension stone sold or used by domestic producers, including exports. The largest uses and distribution of rough stone, by tonnage, were in building and construction (58 percent), and in irregular-shaped stone (31 percent). Dressed stone was sold for ashlars and partially squared pieces (43 percent), curbing (19 percent), and flagging (11 percent) by tonnage.

Foreign trade

The preliminary 2016 estimate of the value of total imports into the United States was $2.6 billion — up from the $2.35 billion value of 2015. Of the $2.6 billion import value, dimension granite accounted for about $1.34 billion. Principal import sources for dimension stone, in descending order of value, were China, Brazil, Italy and Turkey. The preliminary 2016 estimate of the value of U.S. exports shows a decrease to $63 million from $75 million in 2015. Principal export destinations for dimension stone were, in descending order of value, China, Italy and Canada.

Outlook

The United States is one of the world's leading markets for dimension stone. Slow growth in the U.S. economy in 2016, coupled with mixed to moderate growth in new residential construction, resulted in lower domestic production of dimension stone compared with the previous year. Dimension stone for construction and refurbishment was used in commercial and residential markets; in 2016, the refurbishment and remodeling market of existing homes was healthy and robust compared with that of 2015. These conditions contributed to a steady rise in dimension stone imports. Apparent consumption, by value, was estimated to be $3 billion in 2016 — a 9 percent increase from that of 2015.

The dimension stone industry continued to be concerned with safety and health regulations and environmental restrictions in 2016, especially those concerning crystalline silica exposure. In 2016, the U.S. Occupational Safety and Health Administration finalized new regulations to further restrict exposure to crystalline silica at quarry sites and other industries that used materials containing it. Phased implementation of the new regulations are scheduled to take effect from 2017 through 2021. ■

FIRE CLAY

by Daniel M. Flanagan, National Minerals Information Center, U.S. Geological Survey

Fire clay was the dominant clay type mined in the United States prior to the 1940s and accounted for nearly 70 percent of the total clay tonnage produced from 1900 through 1939 (Fig. 1). Domestic production of fire clay (the quantity sold or used by producers) increased sharply from the beginning of U.S. involvement in World War II through the immediate post-war period, peaking at 10.8 Mt (11.9 million st) in 1951, then began to steadily decrease after 1956. In every year since 1986, fire clay sales have been lower than those in 1900. Much of the decline may be attributed to greater use of higher-alumina clays, nonclay refractory products and monolithic refractory products to reduce fuel costs and adapt to changing furnace operation requirements.

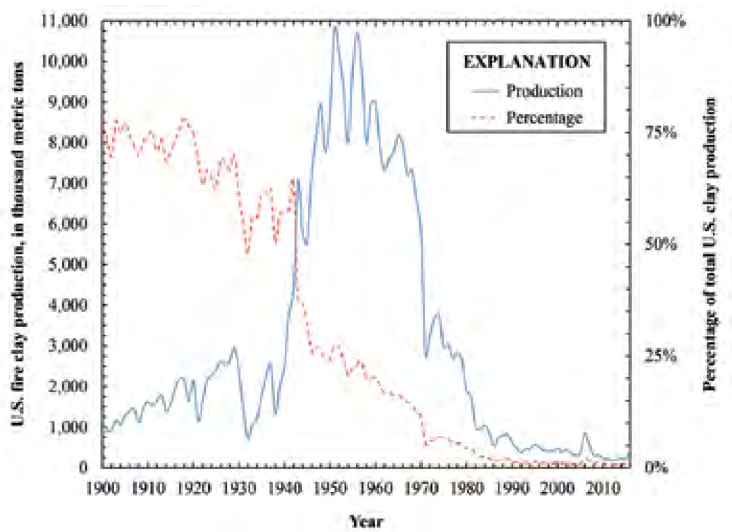
Five companies (Cedar Heights Clay Co., Christy Minerals Co., Elgin-Butler Co., General Shale Brick, Inc. and HarbisonWalker International) were thought to mine fire clay in the United States during 2016. Other companies may or may not have produced fire clay, because year-to-year output has become variable in recent years as fire clay producers randomly entered and exited the market in response to short-term customer demands. In 2016, fire clay production was an estimated 448 kt (494,000 st) valued at $5.04 million compared with 225 kt (248,000 st) valued at $3.18 million in 2015. Missouri likely was the leading producer state, followed by, in descending order of tonnage, Colorado, Ohio and Texas. Preliminary production data for 2016 were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration. Reliable data on global output of fire clay are not available because many countries either do not report clay production or do not distinguish between fire clay and other clay types.

Consumption

Domestic markets for fire clay in 2015 were, in descending order of tonnage, portland cement, refractory grogs and calcines, ceramic floor and wall tile, firebrick, common brick, unclassified products, miscellaneous ceramics, pottery, and miscellaneous refractories. Fire clay sales data reported to the U.S. Geological Survey were mostly withheld to avoid

Figure 1

U.S. fire clay production (sold or used by producers) and share of the domestic production of all clay types, 1900 through 2016.



disclosing company proprietary data, but heavy-clay products (common brick and portland cement) represented nearly 40 percent of sales and refractories accounted for less than 40 percent. The end-use distribution for 2016 was expected to be similar to that of 2015.

Prices

The average unit value of fire clay was estimated to be $11/t ($10/st) in 2016, with unit values for individual operations ranging from $10 to $17/t ($9 to $15/st). The price of fire clay has trended downward since 2007, when the average unit value was $42/t ($38/st). The average free alongside ship value of exported fire clay was estimated as $113/t ($102/st) in 2016, up from $102/t ($92/st) during the prior year, and the average customs value of imported fire clay was $290/t ($263/st), up from $171/t ($155/st). Average unit values for exports and imports typically fluctuate from year to year owing to the influence of small, high-value shipments.

Foreign trade

Fire clay exports were estimated to have decreased by 8 percent in 2016 to 57.3 kt (63,200 st) valued at $6.45 million from an estimated 62.6 kt (69,000 st) valued at $6.37 million in 2015. The U.S. Census Bureau reported that an additional 127 kt (140,000 st) valued at $29.9 million was exported from Charleston, SC, and Savannah, GA, but these shipments likely were refractory-grade kaolin based on the ports' proximity to the kaolin industry and their distance from the fire clay producers. The principal destinations for U.S. exports of fire clay and refractory kaolin in 2016 were Mexico (37 percent), the Netherlands (20 percent), Japan (13 percent), France (9 percent) and Taiwan (5 percent). Imports of fire clay totaled 22 kt (24,300 st) valued at $6.4 million, a decline of 45 percent from 40.3 kt (44,400 st) valued at $6.9 million in 2015. Fire clay imported into the United States primarily originated in Singapore (58 percent) and China (41 percent).

Outlook

Sales of fire clay for refractory uses may rise over the next several years based on expected production increases in the applications that use refractory brick, such as the aluminum, cement, glass, lime, and steel industries. Growth in domestic construction spending over the past several years and a rise in U.S. housing starts in early 2017 suggest that sales of fire clay for heavy-clay products also will increase, but the widespread use of fire clay that took place during the mid-1900s is unlikely to resume. Because the fire clay industry is a mature sector of the U.S. economy, large changes in production and consumption are not expected to occur on a routine basis. ■

FLUORSPAR

by Peter Huxtable, Huxtable Associates, UK

World fluorspar demand continued to decline in 2016 due to weak demand particularly for metallurgical-grade material. Prices fell due to overcapacity exacerbated by the new acidspar output since late 2014 from Vietnam — and some producers shutdown (Bulgaria and Kenya) — while others reduced output, notably Mexico and Mongolia with production closer to 50 percent of more recent output rates. Acidspar prices continued to decline, much reduced from the highs of 2011/2012, and slipped further in 2016 from an average $314/t ($284/st) free on board (f.o.b.) China in 2014, $283/t ($256/st) in 2015 to $241/t ($218/st) in 2016. Metspar prices also slipped further in 2016 despite increased worldwide steel production due partly to competition from alternate fluxes such as alumina-based blends.

Essentially, all fluorspar (CaF_2) consumption in the United States was from imports. Hastie Mining and Trucking Co. produced some fluorspar as a byproduct of its limestone quarry operations in Illinois. In addition, a small amount of usable synthetic fluorspar was produced from industrial waste streams.

World production output has slowly slipped since 2011 (7.3 Mt or 8 million st) to 5.68 Mt (6.2 million st) in 2016 and remains below the pre-recession levels of 2008. The new byproduct output from the Masan Nui Phao tungsten operation in Vietnam remained close to the design output of 200 kt/a (220,000 stpy). Reduced output from Mexico and Mongolia amounted to more than 500 kt (550,000 st), and from China around 300 kt (330,000 st). There was some increases from South Africa, and also some smaller output from new producers in Germany and Spain. Solvay's 30 kt/a (33,000 stpy) Chiprovtsi acidspar plant in Bulgaria closed in January, and the Kenya Fluorspar operation at Eldoret was suspended in April and remained shut down in May 2017.

Table 1

World fluorspar demand.

World demand, Mt	2013	2014	2015	2016
Acidspar	3.49	3.43	3.27	3.49
Metspar	2.98	2.99	2.53	2.24
Total	6.47	6.43	5.80	5.73

Trade

In 2016, U.S. fluorspar imports totaled 383 kt (422,000 st), which included 328 kt (361,000 st) of acid-grade fluorspar (acidspar) and 55 kt (60,000 st) of metallurgical-grade fluorspar (metspar). This was an increase of 2 percent compared with 2015 due to higher metspar while acidspar imports remained unchanged. Mexico was the leading supplier of fluorspar to the United States, accounting for 70 percent of total imports followed by China (12 percent). South Africa provided 8 percent followed by Vietnam (6 percent), Spain (3 percent) and United Kingdom (1 percent).

Leading imports, in descending order of quantity, were from Mexico, 213 kt (234,000 st) of acidspar and 55 kt (60,000 st) of metspar, China 46 kt (50,000 st) of acidspar. South Africa 31 kt (34,000 st) of acidspar, Vietnam 23 kt (25,000 st) of acidspar, Spain 11 kt (12,000 st) of acidspar and United Kingdom 2 kt (2,200 st) acidspar. Fluorspar exports totaled 24 kt (26,000 st) in 2015, all to Canada and almost all re-exports of imported fluorspar.

Net imports of hydrofluoric acid (HF) were 114 kt (125,000 st), up 9 percent on 2015. Net imports of aluminum fluoride (AlF_3) were down again sharply at 2 kt (2,200 st) from 18 kt (19,800 st) in 2015 due to further reductions in aluminium production which fell from 1.6 Mt (1.7 million st) in 2015 to just 800 kt (880,000 st) in 2016.

Consumption and uses

Apparent U.S. consumption of fluorspar in 2016 was estimated at 380 kt (418,000 st) an increase from 370 kt (407,000 st) in 2015 essentially due to a small increase in metspar consumption while acidspar remained essentially unchanged at 328 kt (361,000 st).

Worldwide, the largest traditional markets for fluorspar are for the production of HF (40 percent), AlF_3 and synthetic cryolite (both used in aluminum smelting) (20 percent); and in steelmaking (35 percent). The United States no longer produces AlF_3.

The major end use for HF is in the manufacture of fluorocarbons used predominantly as refrigerants and as foam-blowing agents, in the production of fluoropolymers and fluoroelastomers, chemical derivatives, and for petroleum alkylation, uranium processing, stainless steel pickling, and other diverse uses. In the electrolytic reduction and refining of aluminum, AlF_3 is used as a flux to improve efficiencies by lowering the melting point of the electrolyte mix and by suppressing sodium ions.

HF overall requirement remained relatively flat in 2016 despite increased higher consumption by Japan since 2014. Production continued to increase as a result of the new Gulf Fluor facility in United Arab Emirates (UAE). China provided 40 percent of world output compared to 15 percent in 2002. In 2016, North America provided 29 percent and Europe provided 14 percent of global supply.

Worldwide demand for AlF_3 was unchanged in 2016 at 1.2 Mt (1.3 million st). The 2 percent increase in aluminium production was largely met by consumer stocks. China produced some 70 percent of world output but only 54 percent of the aluminium production, exporting 15 percent of its output. AlF_3 consumption increased again in China, and also in India, Europe and Malaysia but reduced in the United States.

Overall, world fluorspar demand remained unchanged over 2015 with reduced consumption in China and North America offset by increases elsewhere. Future fluorspar demand is closely linked to the health of international economies, although the fluorocarbon market is more problematic as both the European Union and United States introduce more restrictions on the use of certain HFCs and HCFCs due to their global warming potential (GWP). The low-GWP hydrofluoroolefins refrigerant HFO-1234yf is the preferred replacement for HFC-134a by both the U.S. Environmental Protection Agency (EPA) and the EU; however, Daimler in Europe has opted for CO_2-based air-conditioning refrigerant in its 2017 Mercedes E and S class cars.

World fluorspar markets have been on a roller coaster in recent years — strong demand and high prices leading up to the 2008-2009 recession, a major slump during the recession, a strong rebound in 2011-2012, but then a steady fallback since.

Prices

Overall, worldwide acidspar prices continued to weaken after the heights of 2011-2102 when they reached $440/t ($400/st). and continued to fall further in 2016. Metspar prices also deteriorated further in 2016 despite increased steel output largely due to oversupply and some not-in-kind replacement. According to *Industrial Minerals* magazine, 2016 year-end prices for acidspar were — China, dry basis, cost, insurance and freight U.S. Gulf of Mexico port, $260 to $270/t ($235 to $245/st); China, wet filtercake, f.o.b. China port, $250 to $270/t ($227 to $245); Mexico, f.o.b. Tampico, $260 to $280/t ($235 to $254) $254/st for high-arsenic acidspar; and South Africa, dry basis, f.o.b. Durban, $200 to $220/t ($180 to $200/st). The published yearend price for Mexican metspar was $230 to $250/t ($208 to $227/st) f.o.b. Tampico.

China's export data showed f.o.b. acidspar price averaged $241/t ($218/st) compared to $284/t ($257/st) in 2015 and $312/t ($283/st) in 2014. Due to reduced Chinese output this trend reversed by February 2017 and prices rose to a three-year high of $330-340/t ($299 to $308/st). These prices were not matched elsewhere due to overhanging stocks and long-term supply contracts at previously negotiated prices.

Industry news

Hastie Mining and Trucking Co. continued limited fluorspar production from its mine in Kentucky and intends to eventually produce both acidspar and metspar grades.

In Vietnam, Masan Resources' Nui Phao tungsten, copper, fluorspar and bismuth mining project, commissioned mid-2014, continued fluorspar shipments to major markets of some 200 kt (22,000 st) in 2016.

Mexico's output was essentially unchanged at the reduced 600 kt (660,000 st) level apparent from early 2015, against recent more normal 1-1.2 Mt.(1.1 million st to 1.2 million st). Exports of both metspar and acidspar continued lower than in recent years.

South African output returned to a more normal 200 kt (180,000 st) but Mongolia output remained low at 300 kt (330,000 st) much of which was exported to Russia where UC Rusal's 120 kt/a (132,000 stpy) Yaroslavsk operation remained shut down.

Canada Fluorspar Inc. received government approval mid-2016 and continued to develop its new processing plant and surface and underground ore supply. Commissioning is expected in the second half 2017 of the 200 kt/a (220,000 stpy) acidspar project in Newfoundland. In March 2017 both the federal and provincial governments supported the company with loans totaling $22 Mt ($24 million st).

Fluorsid Spa, with 60 kt/a (66,000 stpy) AlF_3 and 10 kt/a (11,000 stpy). HF production facilities in Sardinia and Italy, and the British Fluorspar mine 60 kt/a (66,000 stpy) operation in the United Kingdom, purchased Boliden's 40 kt/a (44,000 stpy) Noralf AlF_3 plant in Odda, Norway for Euro12.5 million effective Dec. 1, 2016.

Trends and outlook

The outlook for steel and aluminum remain strong. For the chemical industry there remain some environmental concerns for fluorine products, most particularly in Europe through the 2014 F-Gas Regulation which became effective January 2015. This aims to reduce F-gas emissions (from high GWP HFCs, perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) by two-thirds of current levels by 2030, which may inevitably lead to some not-in-kind replacements as already planned by Daimler for its Mercedes car range. The U.S. EPA significant new alternatives policy (SNAP) was effective from January 2016 which placed restrictions on the use of several HFCs and HCFCs. Arkema will close its HFC1234a plant at Pierre Benite, France in the first quarter of 2017. Further restrictions on the use of HFCs were agreed by nearly 200 countries at the Montreal Protocol meeting in Kigali, Rwanda in October. The United States and European Union will gradually reduce emissions by 10 percent of 2011-2013 levels by 2019 and 85 percent by 2036.

The U.S. Department of Commerce launched an investigation in October into imports from China of HFC-134a and announced anti-dumping duties effective March 1, 2017.

The acceptance by the European Union, the United States and by the International Panel on Climate Change (IPPC) of refrigerant gas HFO-1234yf with a GWP lower than CO_2 as the preferred car air-conditioning replacement for HFC-134a (banned on new vehicles from January 2017) has encouraged Honeywell to expand production at its Geismar, LA plant; and Arkema to bring capacity on-stream in Asia and then Europe. Chemours is constructing a plant at its Corpus Christi site in Ingleside, TX, due to start production in the second half of 2018 as well as to expand its manufacturing facility in Zhonghao, China. It also has a new HFO-1336mzz (refrigerant and foam expansion agent) production facility as a co-venture with Changsu 3F in Zhonghao.

The growth of fluoropolymers that have captured fluorine in their products, and are outside environmental constraints, remains strong and into fast growing sectors, which include Li-ion batteries, electronics and solar panels. However, there are concerns and increasing restrictions on the use of grease repellant PFCs in fast-food packaging and drinking water. The World Health Organization consider PFOA as a possible carcinogen.

Despite the continued sluggish world growth, demand and acidspar prices are expected to increase in 2017 due to lower overhanging stocks and production and supply in better balance. ■

GEMSTONES

by D.W. Olson, National Minerals Information Center, U.S. Geological Survey

The estimated value of natural gemstones produced from U.S. deposits during 2016 was $8.53 million, a slight decrease from that of 2015. U.S. gemstone production included agate, amber, beryl, coral, garnet, jade, jasper, opal, pearl, quartz, sapphire, shell, topaz, tourmaline, turquoise and many other gem materials.

More than 60 varieties of gemstones have been produced from U.S. mines, but commercial mining of gemstones has never been extensively undertaken in the United States. Most U.S. gemstone production has been from relatively small mining operations, or production has been as a byproduct of the mining of other mineral commodities. In the United States, much of the current gemstone mining is conducted by collectors, gem clubs, and hobbyists, rather than commercial organizations.

The commercial gemstone industry in the United States consists of individuals and companies that mine gemstones or harvest shell and pearl, firms that manufacture synthetic gemstones, and individuals and companies that cut natural and synthetic gemstones. The U.S. gemstone industry is focused on the production of colored gemstones and on the cutting of large diamonds.

During 2016, each of the 50 states produced at least $1,500 worth of gem materials. Twelve states accounted for 91 percent of the total value, as voluntarily reported to the U.S. Geological Survey by survey respondents. These states were, in order of descending value of production, Idaho, Arizona, Oregon, California, Montana, Arkansas, Maine, Colorado, North Carolina, Nevada, Texas and Utah. Some states are known for the production of a single gem material, such as Tennessee for freshwater pearls. Other states, including Arizona, California, Idaho, Montana, Nevada and North Carolina, are known for producing a variety of gemstones. North Carolina is the only state with identified deposits of all four of the most popular precious gemstones: diamond, emerald, ruby and sapphire.

The estimated value of U.S. synthetic or manufactured gemstone production was $57.3 million in 2016. Production value increased about 4 percent from that of 2015. Reported output of synthetic gemstones was, in order of decreasing production value, from six firms in North Carolina, New York, Michigan, South Carolina, California and Arizona. Production included the manufacture of cubic zirconia, diamond, garnet, moissanite, ruby, sapphire and turquoise.

Consumption and uses

Although the United States accounts for only a small portion of the total global gemstone production, it is the world's leading gemstone market. U.S. gemstone markets accounted for more than an estimated 35 percent of world gemstone consumption in 2016. The U.S. apparent consumption for unset ,gem-quality diamond during 2016 was estimated to be about $20.8 billion. U.S. apparent consumption for unset, nondiamond gemstones totaled about $431 million. The major uses for gemstones in the United States were in jewelry, for carvings, and in gem and mineral collections.

Prices

Gemstone prices are governed by many factors and qualitative characteristics, including beauty, clarity, demand, durability, freedom from defects, perfection of cutting and rarity. Colored gemstone prices are generally influenced by market supply-and-demand considerations, and diamond prices are supported by producer controls on the quantity and quality of supply. Diamond pricing in particular is complex; values can vary significantly depending on time, place, and the subjective evaluations of buyers and sellers.

Imports and exports

During 2016, total U.S. gemstone trade (imports plus exports) with all countries and territories was about $46.3 billion. In 2016, U.S. exports and re-exports of diamond were valued at $19.5 billion, and U.S. exports of gemstones other than diamond were valued at $1.62 billion. United States imports of diamond were valued at $23.3 billion, and U.S. imports of gemstones other than diamond were valued at $2 billion.

The United States is a significant international diamond transit center as well as the world's leading gem diamond market. The large volume of re-exports shipped to other centers is one measure of the significance of the United States in the worldwide diamond supply network.

In a four-year average of U.S. import sources by value, the leading gemstone sources were Israel, 37 percent; India, 29 percent; Belgium, 19 percent and South Africa, 4 percent. Diamond imports accounted for 92 percent of the total value of gemstone imports.

Outlook

Overall demand for gem diamonds is expected to rise along with demand for other precious gems as economic conditions continue to improve and luxury purchases increase. Precious colored gemstone demand is likely to increase as the popularity and acceptance of colored gemstones, including diamonds, continues to grow. The United States is expected to continue to dominate world gemstone consumption.

Diamond producers will continue to bring a greater measure of competition to global markets. Increased production and lower prices are expected to create greater competition.

More synthetic gemstones, simulants and treated gemstones continue to enter the marketplace as their popularity increases. This will necessitate more transparent industry standards to maintain customer confidence.

Internet sales of diamonds, gemstones and jewelry increased during 2016. They are expected to continue to increase in acceptance, along with other forms of electronic commerce that emerge to serve the diamond and gemstone industries, as the gemstone industry and its customers become more comfortable with and learn more about new e-commerce tools. ■

GRAPHITE

by Andrew Scogings, CSA Global Pty Ltd

Graphite is an allotrope of carbon, characterized by a hexagonal structure that facilitates easy cleavage and which makes it one of the softest substances known. Graphite is grey to black, opaque, very soft, has a low density and a metallic luster. It is flexible and exhibits both metallic and nonmetallic properties, making it suitable for diverse industrial applications. Physical properties include a specific gravity of 2.2 and a Mohs hardness of 1-2.

Natural graphite occurs in several forms, described as amorphous, flake and vein. Graphite may also be manufactured synthetically from carbon-bearing raw materials such as petroleum coke and tar pitch.

Production of natural graphite

Flake graphite deposits are typically hosted in metamorphic rocks such as gneiss and schist, generally have tabular or lens-like geometry and may be mined opencast, though some high-grade flake graphite deposits are mined underground in Germany, Norway and Zimbabwe. Most flake graphite deposits being mined opencast contain between 5 percent and 15 percent graphite, whereas underground mines have grades of around 30 percent graphite.

Vein deposits have complex geometry, are generally narrow (less than 1 m or 3 ft) and are selectively mined underground in Sri Lanka. Amorphous graphite is mined underground and usually extracted using selective room and pillar mining methods, similar to coal mining.

Natural graphite products generally contain associated mineral impurities, which are referred to as ash. These impurities may include silicate and sulfide minerals such as quartz or pyrite in the case of flake graphite (Fig. 1). Amorphous graphite may contain sedimentary rock impurities such as shale, sandstone, quartzite or limestone.

The most commonly used beneficiation method for flake graphite is flotation, and acids may be used to leach out impurities. The graphite ore is crushed and ground in rod mills in closed circuits with screens, before rougher flotation, followed by several regrind and cleaner flotation stages and final drying, screening and packaging.

Global natural graphite production (of all grades) was stable at about 100 kt/a (110,000 stpy) during the period 1900 to 1930 and started to rise fairly quickly from around 1950, reaching approximately 1.2 Mt (1.3 million stpy) from 2014 onward, at a compound annual growth of about 3 percent since 1950. Flake graphite accounts for about 810 kt (892,000 st), amorphous graphite about 320 kt (352,000 st) and vein graphite around 4 kt (4,400 st). Natural graphite production generally tracks global steel production, as steel making and refractories are the dominant market (Fig 2).

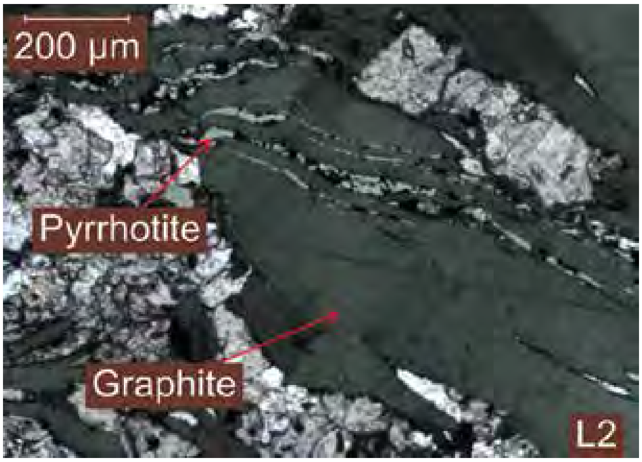
According to U.S. Geological Survey (USGS) data, China was the world's leading producer of natural graphite and supplies about two thirds of the market (approximately 800 kt/a or 880,000 stpy). Brazil (approximately 80 kt of 88,000 stpy), India (approximately 170 kt/a or 187,000 stpy) Canada and North Korea were estimated to have collectively contributed an additional 27 percent of global production. China's production has grown rapidly since 1998, having overtaken the rest of the world in 2000. Production quoted in India has been a topic of discussion for some time and it is believed that the tonnages reported are for run of mine, not for concentrate produced. Therefore, India's production is probably closer to around 25 kt/a (27,000 stpy).

Downstream production is carried out in the United States by specialist processors such as Asbury Carbons, Superior Graphite and GrafTech International. For example, Asbury processes, upgrades and trades many types of carbons including natural and synthetic graphite and sells to a range of end markets including lubricants, refractories and foundry industries. Superior Graphite specializes in electro-thermal purification technologies, engineered graphite electrodes, advanced ceramic shapes and powders, precision particle processing, and carbon coatings. GrafTech International is focused on synthetic graphite products and markets, particularly electrodes but the company also manufactures products based on natural graphite for thermal applications in the electronics industry and for sealants. The company buys flake graphite from sources around the world to manufacture into expandable graphite.

Most spherical graphite for lithium-ion battery anodes is manufactured in China and then exported

Figure 1

Photomicrograph of flake graphite with interleaved pyrrhotite from a Chinese mine.



to Japan or Korea for final coating. The process involves micronizing the graphite flakes, followed by spheronization and purification (acid, alkaline or heating methods) before being coated and made into anodes.

Consumption, uses and specifications

The major uses of graphite are in refractories, batteries, expandable graphite, plus brake linings and steelmaking-foundry operations.

The largest end-market for natural graphite is in refractories, foundries and crucibles used in high temperature environments such as steel, glass and cement production. These markets account for around 40 percent of total graphite consumption; predominately consuming flake and vein graphite.

Metallurgy is the second largest market for natural graphite, which is used in metal production, particularly as a recarburizer in steel and consuming mainly amorphous graphite or fine flake. This accounts for approximately 30 percent of total natural graphite output.

The third largest market for both flake and amorphous graphite is in parts and components; this range of products includes motor vehicle brake pads, carbon brushes for electric motors and pencils. As a group, it is believed to consume about 10 percent of total output.

Batteries are the fourth largest graphite market. Although only consuming around 10 percent of worldwide graphite production, it is potentially the fastest growing market. Chinese producers use minus 100 mesh (94 percent C) small flake for making spherical graphite (for battery anode applications). Anode manufacturers typically blend natural spherical graphite 50:50 with synthetic graphite.

Solid lubricants based mainly on amorphous graphite consume a further 10 percent of production, having been a classic use for centuries.

Expandable graphite is another market that is anticipated to grow, for applications such as fire retardation to replace halogenated retardants, insulation and heat transmission applications. These markets require large flake products generally >80 mesh.

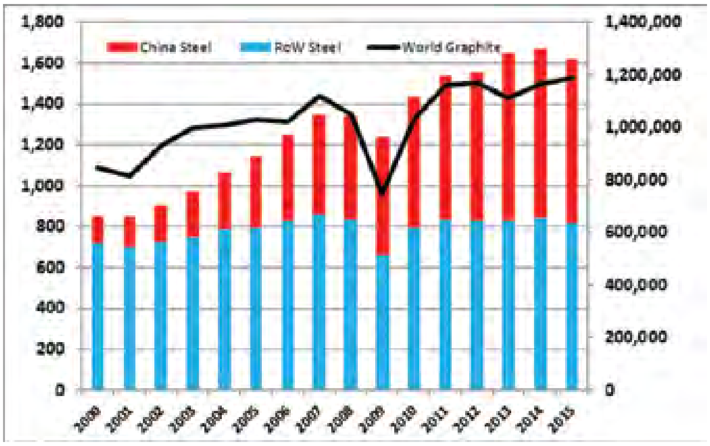
Graphite is typically specified at a minimum by particle size and carbon content (purity). Flake graphite may be described as small, medium or large for example (Table 1). There are no set industry specifications, although in countries such as China the government has established national standards. Other specifications include bulk density, crystallinity and expansion volume.

Trade

The primary producing and exporting countries include China, Brazil, India, North Korea, Mexico and Canada. Imports are dominated by the United States, China (from Korea), Germany, Japan and India, which account for approximately 250 kt/a (275,000 stpy) of global trade.

Figure 2

World natural graphite production relative to steel production from 2000 to 2015. Steel production = 1000s tonnes. Graphite production = tonnes. (Source: USGS and World Steel Association).



China has consistently been the leading global exporter, trading generally more than 300 kt/a (330,000 stpy) since 2000, at prices above $1,000/t ($907/st) since from 2012 to 2015. The United States has consistently been a leading global importer, sourcing about 50 to 70 kt/a (55,000 to 77,000 stpy) since 2000, at prices above $1,000/t ($907/st) since 2010.

Sri Lanka has exported around 4 kt/a (4,400 stpy) of vein graphite in recent years at a price in excess of $1,600/t ($1,450/st) according to United Nations trade data.

U.S. natural graphite imports were approximately 40 kt (44,000 st) in 2016 compared with 47 kt (52,000 st) in 2015 and 70 kt (77,000 st) in 2014. The imports were described by the USGS as being 70 percent flake, 29 percent amorphous and 1 percent lump and chip graphite. China, Canada, Brazil and Madagascar supplied most of the flake graphite; Mexico provided all amorphous graphite and Sri Lanka was the sole source of lumpy and 'chippy' dust (USGS, mcs-2017-graph report).

Prices

According to *Industrial Minerals* Magazine, natural graphite prices in the early part of 2016 ranged from approximately $400/t ($362/st) for amorphous graphite (80-85 percent carbon) to $1,150/t ($1,043/st) for flake graphite +80 mesh (94 to 97 percent Carbon). *USGS 2016 Mineral Commodity Summary* estimated import prices into the United States as $1,360/t ($1,233 st) for flake, $1,820/t ($1651/st) for Sri Lankan lump and chip, and $364/t ($330/st) for amorphous graphite.

Flake graphite prices remained relatively steady until approximately 2005, after which they climbed to 2008 in tandem with increased Chinese steel production. Prices declined in 2009 as a result of the global financial crisis before resuming an upward trend and spiking during 2011/2012. Prices have since declined to 2008 levels due to excess production versus market demand. Amorphous graphite has shown similar trends.

As an example, flake graphite (> 80 mesh, 94-97

Table 1

Flake graphite market terminology.

Sizing	Market terminology
>300 µm (+48 mesh)	Extra-large or 'jumbo' flake
>180 µm (-48 to +80 mesh)	Large flake
>150 µm (-80 to +100 mesh)	Medium flake
>75 µm (-100 to +200 mesh)	Small flake
<75 µm (-200 mesh)	Fine flake

percent carbon) sold for about $750/t ($680/st) up until 2004, before rising to a peak of around $2,500/t ($2,268/st) in 2011/2012 before falling back to $1,000/t ($907/st) in 2014 and is currently in the range $750 to $850/t ($680 to $771/st) (source: *Industrial Minerals* Magazine).

One graphite price not generally quoted is for jumbo flake, a term that describes flakes +35 mesh size or larger. Trade is believed to be relatively limited and that prices may have been around $2,000/t ($1,815/st) in 2016.

Spherical graphite is another product for which prices are not widely publicized. However, according to China Customs data, prices for uncoated spherical product range around $3,000/t ($2,720/st).

Geologic settings and mineral resources

Economic natural graphite deposits occur in three main geologic types: flake graphite disseminated in metamorphosed sedimentary rocks, amorphous graphite formed by metamorphism of coal or carbon-rich sediments, and veins or lump graphite filling fractures in granitic country rock.

The USGS estimated 250 Mt (275 million st) of reserves accounted for by Brazil (72 Mt or 79 million st), China (55 Mt or 61 million st), India (8 Mt or 8.8 million st), Madagascar (1.6 Mt or 1.7 million st), Mexico (3.1 Mt or 3.4 million st), Mozambique (13 Mt or 14.3 million st), Tanzania (5.1 Mt or 5.6 million st) and Turkey (90 Mt or 99 million st).

The past few years have seen intensive exploration for graphite by both private and publicly listed companies, with most exploration aimed at flake graphite deposits. Australia, Canada, Mozambique and Tanzania were the main hotspots, with the biggest resources discovered in northern Mozambique and southern Tanzania. Other target countries have included Brazil, Madagascar, Malawi, Sweden and the United States.

Mineral resources for flake graphite projects reported by publicly traded companies total more than 4.5 Gt (4.9 billion st) of mineralization, at grades ranging from approximately 2 to 25 percent graphitic carbon for an average grade of 9 percent graphitic carbon. The contained graphite is estimated to be approximately 400 Mt (440 million st) of which approximately 300 Mt (330 million st) may be recoverable assuming 30 percent mining and process losses. The largest publicly-reported mineral resources are concentrated in East Africa, mainly in northern Mozambique and southern Tanzania.

Recycling and environmental

There are no graphite mines in the United States so no regulatory or reclamation issues arise. According to the USGS, refractory products led the way in recycling of graphite products, with material being recycled into products such as brake linings and thermal insulation.

Outlook

Global natural graphite production is expected to be similar to 2016, when 1.19 Mt (1.3 million st) were produced (USGS).

While most markets are forecast to remain static, growth is expected to come from the battery anode and expandable graphite markets. The battery market for natural graphite used in spherical graphite has been forecast by various researchers to grow at a compound annual growth rate of around 15 percent, from a base of 60 kt (66,000 st) in 2016 to 220 kt (240,000 st) by 2025. The conversion rate of natural graphite to spherical graphite is about 50 percent, which means that there will be 50 percent of the feed graphite available for other applications.

Between traditional markets, battery markets and expandable graphite markets it may reasonably be expected that additional demand may be in excess of 300 kt/a (330,000 stpy) flake graphite by 2025. ■

GROUND CALCIUM CARBONATE

by J. Gauntt,, Golder Associates Inc.

Calcium carbonate is one of the most widely used industrial minerals in applications such as cement, lime, agriculture, power plant flue gas desulfurization (FGD) and construction aggregates. Most applications are generally high volume and low value ($10/t or $9/st or less free-on-board mine site) uses of this material. Specialty uses of ground calcium carbonate (GCC) are typically referred to as performance mineral or extender and filler applications. Primary specialty markets for GCC include paper and plastics as well as a number of construction applications including joint compounds, carpet backing, paint, and adhesives, caulks and sealants (ACS). Other important specialty applications for GCC include rubber, food and personal care products. A new and growing application for GCC is in non-woven fabrics where this mineral replaces a small percentage of the polymer. Typically specialty applications for GCC are color sensitive and require extremely white/bright materials. Although deposits of limestone are located in most states, high brightness resources are relatively rare and controlled by a limited group of suppliers.

Production and consumption

There are a limited number of GCC producers that produce high-purity white products. The two largest producers, Omya and Imerys, are not only the major producers in North America but are also the most significant global suppliers of GCC. J.M. Huber and Specialty Minerals Inc. (SMI) are the two other large suppliers of white GCC in the United States. Suppliers that have a more limited market share, particularly in higher value applications, include Columbia River Carbonates, Lhoist, Carmeuse and Oldcastle Materials. Finally, there are a number of small suppliers that essentially have one operation that service local markets where coarse products are used, none of which have significant market share.

The market for GCC in the United States appears to have grown again in 2016 as it has the last several years. Although no official statistics are publicly available, SMI's revenue from GCC sales increased almost 4 percent in 2016 compared to the previous year. Further, in Mineral Technologies third quarter report (the owner of SMI), it is specifically stated that the growth in SMI's processed minerals division was primarily attributed to growing GCC volume. A steady firming of new U.S. housing construction is a key driver of this growth.

Construction materials account for the largest volume of GCC consumption in the United States. The leading end-use in this segment is joint compounds. Large joint compound producers like U.S. Gypsum, National Gypsum and Georgia Pacific formulate joint compound with as much as 80 percent GCC by weight. Carpet producers use GCC as a filler in backing materials. Latex and GCC are mixed and constitute the bottom layer of most carpets.

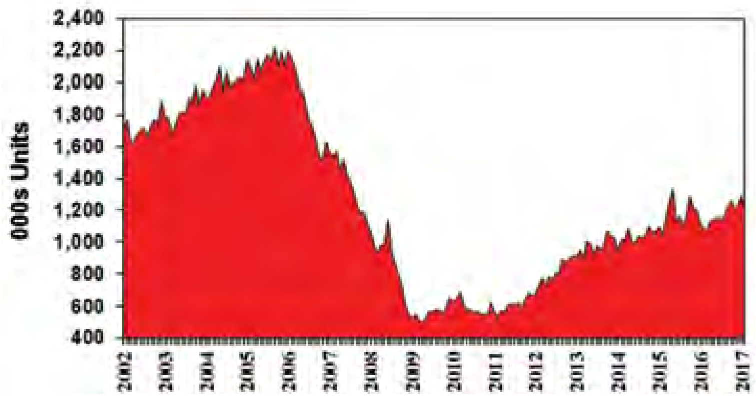
Paint is another important construction application for GCC. The primary application is architectural (house) paint. Many architectural paint formulations use a fine and a coarse grade to improve particle packing. Other important uses in this market include traffic paint, powder coatings and stucco.

ACS applications for GCC cover a range of products but most are used in commercial construction. A typical application is silicone caulk used to install windows in an office building. Because of the critical performance nature of such products, once a material is specified, it is extremely difficult for a new supplier to replace an existing source.

Plastic applications have been one of the fastest growing segments for GCC during the last two decades. It is used extensively in polyvinyl chloride (PVC) in both pipe and siding. GCC in PVC provides impact strength, stiffness and heat

Figure 1

U.S. monthly new housing permits annualized rate 2002 to 2017.



resistance. Polyethylene (PE) films are another significant plastics segment for GCC in which this mineral reduces costs for items like trash bags. Polyester consumes significant volumes of GCC for automotive, appliance and bathroom products. PVC and PE typically use ultrafine, surface-treated products like Supercoat from Imerys or Omyacarb UF from Omya. Polyester-based cultured marble products, widely used in bathroom countertops and shower stalls, use medium grades of dry ground products but have very high brightness requirements. A growing application, developed by Imerys, is the use of GCC in non woven fabrics.

Paper is another important market for calcium carbonate. Globally, paper is the leading specialty market for GCC. In addition to GCC, paper uses large quantities of precipitated calcium carbonate (PCC). Typically, PCC suppliers locate plants adjacent to paper mills to minimize logistics costs. PCC also uses lime as a feedstock versus limestone for GCC. The development of onsite PCC plants at paper mills has been one of the most dramatic developments in the use of minerals in paper during the last several decades. This was a technology-driven development as the industry converted from an acidic based system to alkaline processing. In many cases carbonate was then able to replace more expensive kaolin clays, particularly as a filler mineral in paper. PCC is currently the mineral filler of choice in the uncoated wood-free paper market. Alternatively, GCC is preferred in coated paper, where it can be applied at high solids and exhibits good viscosity and flow properties.

Other important uses of GCC include rubber, food and personal care products. Typical rubber applications include floor mats and footwear with limited quantities used in wire and cable, belts and hoses, and mechanical rubber goods. GCC is used in a number of food products as a supplemental calcium source. Acid based chewing gum also uses GCC as a filler product. Finally, GCC is also used as a dusting agent in underground coal mines.

Pricing

Generally, prices for the applications reviewed in this article range between $22 and $220/t ($20 and $200/st). In a number of niche applications, GCC prices exceed $330/t ($300/st).

In terms of pricing changes in 2016, on Sept. 1, Imerys announced an increase in GCC prices ranging between 2 and 10 percent effective Dec. 1. On Dec. 2, J.M. Huber announced a price increase for GCC ranging between 5 and 10 percent effective Jan.1, 2017. Huber indicated cost increases in materials, packaging, freight, regulatory compliance, labor and capital were factors that contributed to the need for a price increase. None of the other large producers of GCC in the United States made public announcements on pricing for GCC in the United States in 2016.

New developments and outlook

Because the GCC business is so heavily influenced by the residential construction market, the industry continues to witness far less demand compared to earlier this century. U.S. housing construction has gradually improved and in 2016 was at a level of 1.2 million units. This was the highest annual housing construction level since 2007 as outlined in Fig. 1. Housing has improved significantly and is more than double what it was in 2009/2010.

With interest rates still relatively low and demand for housing in many metropolitan areas firming, 2017 should be another good year for the GCC business in the United States. Consumption growth at or slightly above GDP seems realistic. ■

GYPSUM

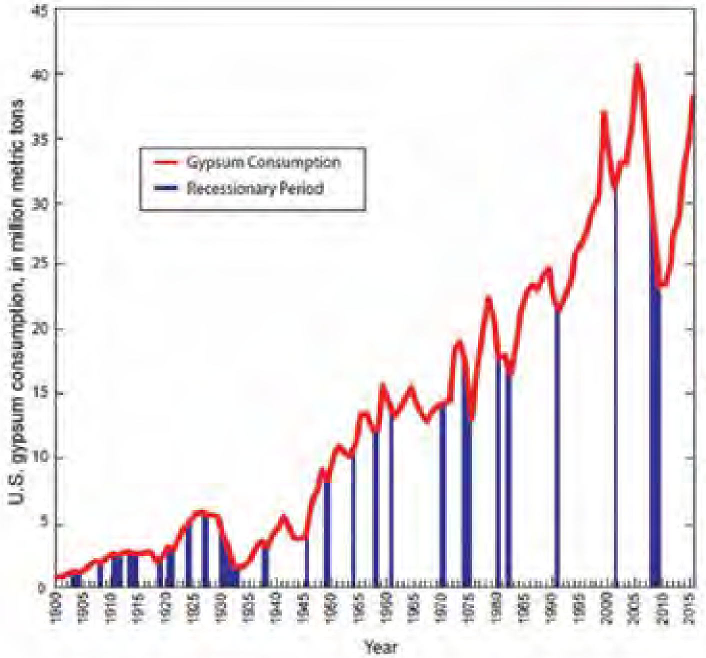
by R.D. Crangle Jr., National Minerals Information Center, U.S. Geological Survey

The United States is the world's third-ranked producer and consumer of gypsum behind China and Iran. Production of mined crude gypsum in the United States during 2016 was estimated to be 15.5 Mt (17.1 million st), a slight increase compared with 2015 production. The average price of mined crude gypsum was $9/t ($8.16/st). Synthetic gypsum sales in 2016, most of which were generated as a flue-gas desulfurization product from coal-fired electric powerplants, were estimated to be 17 Mt (19 million st) and priced at approximately $5/t ($4.54/st). Forty-seven companies mined gypsum in the United States in 16 states. U.S. gypsum exports totaled 42 kt (46,000 st). Imports were 4.3 Mt (4.7 million st).

As a low-value, high-bulk commodity normally mined in openpit operations from deposits widely distributed throughout the world, gypsum tended to be consumed within the many countries where it was produced rather than exported. Less than 20 percent of the world's crude gypsum production was estimated to enter international trade. Only a few countries, such as Canada, Mexico, Spain and Thailand, were major crude gypsum exporters. Of these, Canada and Mexico were significant exporters because of their large deposits in proximity to gypsum-consuming facilities in the United States.

Figure 1

Gypsum consumption and economic recessions since 1900. Sources: U.S. Bureau of Labor Statistics, U.S. Census Bureau, U.S. National Bureau of Economic Research, U.S. Geological Survey.



Consumption

An estimated 20 Mt (22 million st) of gypsum-derived products, including agricultural supplements, cement, plasters and wallboard were produced in 2016 with an estimated value of $3.5 billion. Demand for gypsum depends principally on the performance of the building construction industry, particularly in the United States, where about 95 percent of consumed gypsum is used for building plasters, the manufacture of portland cement and wallboard products. Gypsum has no practical substitute in manufacturing portland cement. Since 1900, pronounced decreases in gypsum consumption have traditionally preceded periods of economic recession (Fig. 1).

Trade

World gypsum reserves are large in major producing countries, but data for many countries are not available. Domestic gypsum resources are adequate but unevenly distributed. Synthetic gypsum, most of which is byproduct from coal-fired powerplants, coupled with substantial imports from Canada, augment U.S. domestic crude gypsum supplies for wallboard manufacturing in the United States, particularly in the Eastern and Southern coastal regions. Imports from Mexico supplement domestic supplies for wallboard manufacturing along portions of the U.S. Western seaboard. Large gypsum deposits occur in the Great Lakes region, the midcontinent region, and several Western states. Foreign resources are large and widely distributed; 81 countries are known to produce gypsum.

Synthetic equivalents

Synthetic gypsum is very important as a substitute for mined gypsum in wallboard manufacturing, cement production and agricultural applications (in descending order of tonnage). In 2016, synthetic gypsum accounted for more than 50 percent of the total domestic gypsum supply.

Outlook

Some of the more than 4 Mt (4.4 million st) of gypsum scrap that was generated by wallboard manufacturing, wallboard installation and building demolition was recycled. Recycled gypsum was used primarily for agricultural purposes and feedstock for the manufacture of new wallboard. Other markets for recycled gypsum include athletic field marking, cement production as a stucco additive, grease absorption, sludge drying and water treatment.

The use of synthetic gypsum may continue to grow, albeit at a slower pace. As power companies convert electrical generation plants to natural gas to take advantage of inexpensive and plentiful shale gas, the production of synthetic gypsum could decline because fewer coal-fired powerplants would be operating. Nevertheless, the use of synthetic gypsum by U.S. wallboard manufacturers is likely to continue. Similarly, should the economy continue to expand, and if residential and commercial construction continues to increase, as documented by housing starts that have increased each year since 2010, gypsum consumption is also expected to increase in the near future. ■

INDUSTRIAL DIAMOND

by D.W. Olson, National Minerals Information Center, U.S. Geological Survey

Estimated 2016 world production of natural and synthetic industrial diamond was about 4.46 billion carats. Natural diamond resources have been discovered in more than 35 countries. At least 15 countries have the technology to produce synthetic diamond. During 2016, natural industrial diamonds were produced in at least 12 countries and synthetic industrial diamond was produced in at least nine countries. About 97 percent of the combined natural and synthetic global output was produced in China, Ireland, Russia, South Africa and the United States. During 2016, China was the world's leading producer of synthetic industrial diamond followed by the United States and Russia. In 2016, the two U.S. synthetic producers, one in Pennsylvania and another in Ohio, had an estimated output of 125 million carats (Mct), valued at about $123 million. This was an estimated 41.6 Mct of synthetic diamond bort, grit, and dust and powder with a value of $21.9 million combined with an estimated 83.2 Mct of synthetic diamond stone with a value of $101 million. Also in 2016, nine U.S. firms manufactured polycrystalline diamond (PCD) from synthetic diamond grit and powder. The U.S. Government does not collect or maintain data for either domestic PCD producers or domestic chemical vapor deposition (CVD) diamond producers for quantity or value of annual production. Current trade and consumption quantity data are not available for PCD or for CVD diamond. For these reasons, PCD and CVD diamond are not included in the industrial diamond quantitative data reported here.

An estimated total of 66.5 Mct of used industrial diamond, valued at $4.13 million, was recycled in the United States during 2016. This was an estimated 66.3 Mct of recycled diamond bort, grit and dust and powder with a value of $3.64 million combined with an estimated 195,000 carats of recycled diamond stone with a value of $486,000. Lower prices of newly produced industrial diamond appear to be reducing the number and scale of diamond stone recycling operations. Most of this recycled material was recovered from used drill bits, diamond tools and other diamond-containing wastes. Some diamond also was recovered from residues generated in the manufacture of PCD.

Since its introduction in the mid-1980s, CVD diamond has seen strong growth. The global market value of industrial diamond and diamond-like films and coatings was estimated to have been more than $1 billion in 2016. Early applications for CVD diamond focused largely thin- and thick-film PCD for cutting tools and dressing applications owing to the mechanical properties of diamond. Newer applications that use CVD diamond's mechanical properties include wear parts, such as watch gears and chemical mechanical polishing pad conditioners. CVD diamond is being used in microelectronic components, such as high-speed processors, medical devices, wide bandgap radio frequency and power conversion devices and optoelectronic devices (light emitting diodes, laser diodes) that generate exceptionally high heat densities that require innovative approaches to thermal management. Boron-doped diamond (BDD) electrodes for water treatment are attracting significant interest because of diamond's potential as an environmentally friendly, high performance electrode material. BDD electrodes have many characteristics that make them ideal for eliminating organic contaminants from water.

Historically, diamond has been perceived as an expensive material. Advances in CVD diamond manufacturing, like the development of microwave carbon plasma technology and the development of higher-throughput hot filament CVD diamond reactors, have significantly reduced diamond costs. This has led many industries to revisit development activities and actively pursue the use of CVD diamond for a growing number of applications.

One U.S. company was developing projects using single-crystal CVD diamond materials in high-voltage power switches, lasers, quantum communications and computing and water treatment and purification. These projects could translate into $1 billion-plus market opportunities and high-volume technology applications.

Consumption

The United States remained one of the world's leading consumers of industrial diamond. Estimated U.S. apparent consumption of natural and synthetic industrial diamond stones, bort, grit and dust and powder was 293 Mct, valued at $139 million. Industrial diamond is used for applications such as truing and dressing grinding wheels, production of fine wire, waterjet nozzles for material cutting, direct precision cutting and material processing, material testing, drilling, grinding, polishing, and finishing materials. The major domestic industries that consume industrial diamond are construction, machinery manufacturing, mining services (drilling), oil and gas exploration (drilling), stone cutting and polishing, and transportation systems (infrastructure and vehicles). Stone cutting and highway building and repair together made up the largest demand for industrial diamond. During 2016, about 99 percent of the industrial diamond market used synthetic industrial diamonds because the diamond quality can be controlled and properties can be customized to fit specific requirements.

Prices

Natural and synthetic industrial diamonds differ significantly in price. Natural industrial diamond normally has a more limited range of values, from about $0.45 per carat for bort size material to about $1.55 to $13.20 per carat for most stones, with some larger stones selling for $200 per carat or more. Prices of synthetic diamond vary according to size, shape, crystallinity, and the absence or presence of metal coatings. In general, prices for synthetic diamond produced in the United States for grinding and polishing range from as low as $0.44 per carat to $1.57 per carat. Strong and blocky material for sawing and drilling sells for $2.40 to $4.00 per carat. Large, synthetic crystals with excellent structure for specific applications sell for several hundred dollars per carat. During 2016, U.S. imports of all types of industrial diamond had an average value of $0.31 per carat. These imports were a combination of imports of diamond bort, grit, and dust and powder (natural and synthetic) that had an average value of $0.23 per carat and imports of diamond stone (natural and synthetic) that had an average value of $13.20 per carat.

Foreign trade

During 2016, the United States led the world in industrial diamond trade. U.S. imports of industrial-quality diamond stones (natural and synthetic) were about 1.42 Mct valued at about $18.6 million. U.S. imports of industrial-quality diamond dust, grit, and powder (natural and synthetic) were about 217 Mct valued at about $49.2 million. During 2016, the United States did not export industrial diamond stones. U.S. exports of industrial diamond dust, grit, and powder (natural and synthetic) were about 116 Mct valued at $56 million.

Outlook

The United States is expected to continue to be one of the world's leading consumers of industrial diamond into the next decade and likely will remain a significant producer and exporter of synthetic industrial diamond as well. U.S. demand likely will increase as the economy continues to improve. Demand for synthetic diamond grit and powder is expected to remain greater than that for natural diamond material. Constant-dollar prices of synthetic diamond products, including CVD diamond films, are expected to continue to decline as production technology becomes more cost effective; the decline is even more likely if competition from low-cost producers in China and Russia continues to increase. ■

INDUSTRIAL GARNET

by D.N. West, National Minerals Information Center, U.S. Geological Survey

Garnet has been a popular gemstone throughout history since the Bronze Age. Garnet's angular fractures, relatively high hardness and specific gravity, chemical inertness and nontoxicity also make it ideal for many industrial applications. In addition, it is free of crystalline silica and can be recycled. Garnet is the general name given to a group of complex silicate minerals, all with an isometric crystal structure and similar physical properties and chemical compositions. Higher quality industrial garnet is used as a loose grain abrasive because of its hardness, and lower quality industrial garnet is used as a filtration medium because it is relatively inert and resists chemical degradation. Garnet is also beginning to be used as an oil and gas reservoir fracturing proppant, which may be mixed with other proppants when high temperature effects are encountered or in deep formations.

Production

In 2016, U.S. production of crude garnet concentrate for industrial use was estimated to be 52.3 kt (57,600 st) valued at about $7.7 million, a 6 percent decrease in quantity compared with 2015 production. These estimates were derived by combining reported company data with information from the U.S. Mine Safety and Health Administration and information from garnet industry consultants. Refined garnet material sold or used was estimated to be 38 kt (42,000 st) valued at $11 million, which was unchanged from the previous year. In 2016, industrial garnet was mined by four firms in New York, Montana and Idaho, in descending order of tonnage. The majority of industrial grade garnet mined in the United States is almandite (iron aluminum silicate). Some andradite (calcium iron silicate) also is mined domestically for industrial uses.

Total world industrial garnet production was estimated to be about 1.7 kt (1,870 st). India, China and Australia, in descending order of tonnage, were the leading producers in 2016. The United States produced about 3 percent of the industrial garnet mined worldwide.

Consumption

In 2016, the United States, with an estimated 201 kt (221,000 st) of apparent consumption, was one of world's leading users of industrial garnet, consuming 12 percent of global garnet production. U.S. garnet consumption decreased by 28 percent compared with that of 2015. Since 2010, U.S. garnet consumption has nearly tripled, as new uses have been found for garnet and as garnet has displaced other abrasives. The major end uses for garnet in the United States are, in descending order by estimated market share, waterjet cutting, abrasive blasting media, water filtration, abrasive powders and other end uses. Domestically, the industrial sectors that consume garnet include aircraft and motor vehicle manufacturers, ceramics and glass producers, electronic component manufacturers, water filtration plants, the petroleum industry, shipbuilders and wood-furniture-finishing operations.

Prices

The price of industrial garnet depends on application, quality, quantity purchased, source, and type and therefore encompasses a range of prices. During 2016, estimated domestic values of crude concentrates for different applications ranged from about $134/t to $156/t ($122 to $142/st), with an average of $151/t ($137/st). The domestic values of refined garnet for different applications sold during the year ranged from $245/t to $267/t ($222 to $243/st), with an average of $255/t ($231/st). The average value of garnet imported into the United States during 2016 was $201/t ($182/st).

Foreign trade

The garnet market is very competitive. Lower-priced foreign imports slowly began displacing U.S. production in domestic markets during the 1990s. Since that time, the United States has become increasingly dependent on foreign sources of garnet to meet its consumption needs. In 2016, the United States remained a net importer, with a net import reliance of 74 percent of apparent consumption.

U.S. imports and exports in 2016 were estimated to be 151 kt and 2.38 kt (166,000 and 2,600 st), respectively. Imports decreased by 36 percent, and exports decreased by 84 percent compared with those of 2015. Australia provided about 48 percent; India, 46 percent and the remainder was from several other countries. Australia, Canada, and India continued to gain importance as sources of garnet imports into the United States. Most U.S. exports of garnet were shipped to Asia, Canada, the Caribbean region and Europe.

Outlook

In recent years, the garnet industry has encountered higher production costs and tighter profit margins, which resulted in the loss of noncompetitive producers. To increase profitability and remain competitive with foreign imported material, production may be restricted to only high-grade garnet ores or those deposits that contain other salable mineral products, such as kyanite, marble, mica minerals, sillimanite, staurolite, wollastonite, or metallic ores. Worldwide industrial garnet demand is expected to continue to increase, with the highest growth in markets for waterjet cutting and blasting. ■

INDUSTRIAL SAND AND GRAVEL

by Thomas P. Dolley, National Minerals Information Center, U.S. Geological Survey

Production of industrial sand and gravel (or silica sand) in the United States decreased to an estimated 91.7 Mt (101 million st) in 2016, down by about 11 percent from that of 2015. The estimated value of production of industrial sand and gravel was $4.3 billion in 2016, also a decline of 11 percent from the previous year. A continuing driving force in the industrial sand and gravel industry was the production and sale of hydraulic fracturing sand (frac sand), despite challenging conditions in the global oil and natural gas market. Production of frac sand and well-packing and cementing sand in 2016 was estimated to be 66 Mt (73 million st), about 12 percent less than that of 2015.

In 2016, industrial sand and gravel was produced by 254 companies with 347 operations in 35 states. The top 10 states for the production of industrial sand and gravel were, in descending order by tonnage, Wisconsin, Illinois, Texas, Missouri, Minnesota, North Carolina, Michigan, Oklahoma, Louisiana and Arkansas. Combined production from these states accounted for 82 percent of domestic production in 2016. The United States was the world's leading producer and consumer of industrial sand and gravel, based on estimated world production figures.

Consumption

In 2016, consumption of industrial sand and gravel in the United States was about 89.4 Mt (98.5 million st), a 10 percent decrease from that of the previous year. Major markets for industrial sand and gravel were abrasives, ceramics, chemicals, fillers (ground and whole grain), container glass, filtration, flat and specialty glass, foundry, hydraulic fracturing, recreational uses and silicon metal applications.

Price

The estimated average unit value of domestically produced industrial sand and gravel in 2016 was $46.62/t ($42.30/st) compared with $47.10/t ($42.73/st) in 2015.

Foreign trade

Although the United States remained a net exporter of industrial sand and gravel, exports decreased by 32 percent in 2016 to 2.6 Mt (2.8 million st), with about 85 percent going to Canada. In 2016, imports decreased to about 280 kt from 290 kt (308,000 from 319,000 st) in 2015. Imports of industrial sand and gravel are generally of two types — small shipments of very high-quality silica sand or a few large shipments of lower grade silica sand shipped under special circumstances (for example, very low freight rates). Major import sources for silica sand into the United States were Canada, Japan and Mexico.

Outlook

Mine output of industrial sand and gravel are sufficient to accommodate many end uses for the foreseeable future. Diminished demand for frac sand to support production of natural gas and petroleum from shale deposits was a direct result of declining world oil and gas prices. However, frac sand's relative low cost when compared with that of other proppants, coupled with more efficient hydraulic fracturing techniques, which require greater volumes of silica sand per well, could help maintain demand for frac sand, albeit not at the levels of the past several years.

The industrial sand and gravel industry continued to be concerned with safety and health regulations and environmental restrictions in 2016, especially those concerning crystalline silica exposure. In 2016, the U.S. Occupational Safety and Health Administration finalized new regulations to further restrict exposure to crystalline silica at mine sites and other industries that use it. Phased implementation of the new regulations are scheduled to take effect from 2017 through 2021. ■

IODINE

by Stanley T. Krukowski, Oklahoma Geological Survey

Elemental iodine, chemical symbol I, has an atomic number of 53 and is the heaviest of the naturally stable halogens. As a crystalline solid, it is bluish-black with sub-metallic luster. Iodine has a specific gravity of 4.93 and volatilizes (sublimates) at ordinary room temperatures into a blue-violet gas with an irritating odor. Iodine gets its name from the Greek *ioeides*, which means purple or violet. Iodine is the least active of the halogens, all of which readily displace it. Only slightly soluble in water, iodine also dissolves in alcohol, carbon disulfide, carbon tetrachloride, and chloroform, yielding a deep violet solution. The only stable isotope of iodine is I127, although 37 isotopes are known to exist.

Sources

Two primary sources of iodine production are subsurface brines associated with oil and natural gas deposits and co- and byproducts from nitrate deposits in Chilean desert caliche. The largest iodine resource is seawater. Estimates of iodine resources in seawater vary, but may contain approximately 0.05 to 0.06

ppm. Seaweed of the family *Laminaria* extracts and accumulates from seawater up to 0.45 percent iodine on a dry weight basis. Prior to 1959, seaweed was an important source of iodine, but production from other sources is more economical. Seaweed remains a significant source of iodine in the diets of many populations throughout the world.

International production

The U.S. Geological Survey (USGS) estimated 2016 world production of iodine at 31.6 kt (34, 833 st), excluding U.S. production. The USGS withheld 2016 U.S. production figures to avoid disclosing company proprietary data.

Chile has the largest iodine production and reserves, accounting for almost 66.5 percent of world production (excluding U.S. production). The USGS estimated 2016 Chilean iodine production at 21.0 kt (23,148 st) and 2015 production at 20 kt (22,400 st). Chile produces iodine from iodate minerals as either co- or byproducts of nitrate production, so most iodine plants are adjacent to nitrate plants. Some stand-alone installations, however, are near older nitrate tailings that have high iodate concentrations.

Japan accounts for more than 31 percent of global iodine production (excluding U.S. production). The USGS estimated 2016 Japanese iodine production at 9.8 kt (10,802 st) and 2015 production at 9.8 kt (10,802 st). Companies in Chiba Prefecture account for about 80 percent of Japanese production. Japan produces iodine from sodium iodide solutions found in brines associated with oil and natural gas fields.

The USGS estimated the remaining 2.5 percent of worldwide iodine production (excluding U.S. production) is from, in descending order, Turkmenistan, Azerbaijan and Indonesia. Production from China and Russia was recorded as not available and zero, respectively, for 2015 and 2016. According to Iran's *Financial Tribune*, two companies there produce 230 t/a (253 stpy) of iodine crystal. Azerbaijan, Indonesia, Iran, Turkmenistan and Uzbekistan produce iodine from subterranean brines.

International operations

Sociedad Quimica y Minera de Chile S.A. (SQM), the world's largest supplier of iodine, competed for market share with its closest rival, Cosayach, throughout 2016. Both implemented plans to increase product quality and production efficiencies while lowering production costs. An SQM press release reported its iodine production capacity at 11 kt/a (12,125 stpy), including 9 kt (9,920 st) from its Nueva Victoria plant. Cosayach's website reports a goal of 6 kt/a (6,613 stpy) from its three iodine plants.

In 2016, SQM continued to face accusations concerning possible aquifer depletion by the company in the Atacama Desert. Also, the Chilean economic development agency, Corporacion de Fomento de la Produccion (CORFO), claimed that SQM violated its lease agreement in extracting lithium from CORFO land. CORFO claims SQM sold its products below market value to avoid rental payments that are based on sales revenue. Arbitration proceedings that began in May 2014 continue between the two.

June 2016 was the first report of KSV Kofman Inc. as receiver of RB Energy Inc., owner of Atacama Minerals Chile (AMC). AMC produced 1.1 to 1.2 kt/a (roughly 1,212 to 1,323 stpy) iodine at its Aquas Blancas plant. With RB Energy in receivership, the plant is up for sale. As global iodine prices declined, the Kofman report assessed AMC's financial performance as deteriorated with concurrent erosion of the balance of its equity.

Construction began in the Okarem region of Turkmenistan to increase iodine production capacity from 500 to 1 kt/a (551 to 1,102 stpy). The Iodobrom Scientific Production Association developed the project and the Senagatchilar consortium purchased equipment from Iran to assemble the plant.

Domestic production

Although the USGS did not cite U.S. iodine production values due to proprietary concerns, Iofina plc, reported its 2016 U.S. iodine production of 474.2 t (522.7 st) on its website. Additionally, Oklahoma's *The Journal Record* reported president and chief executive officer of Woodward Iodine Corp., Leroy Goodman, said that three Oklahoma producers account for about 10 percent of global iodine supply. The U.S. produces iodine from sodium iodide solutions found in brines associated with oil and natural gas fields.

Domestic operations

Four U.S. companies accounted for 100 percent of domestic elemental iodine production. IOCHEM, a subsidiary company of Toyota Tsusho America, Inc., owns the largest U.S. iodine plant near Vici, OK. Its annual production capacity is 1,200 t (1,322 st). A long-term contract with Schering AG of Germany accounts for the majority of IOCHEM's output.

Woodward Iodine Corp. (WIC) near Woodward, OK, is owned by Ise Chemicals Corp. of Japan. The WIC iodine plant has production capacity of 800 t/a (881 stpy). MIC Specialty Chemicals (a subsidiary of Mitsubishi International) exclusively distributed the iodine produced by WIC.

Iodine produced in Oklahoma from IOCHEM and WIC comes from brines in the Morrow Formation (Pennsylvanian). Brines contain iodine concentrations of about 300 ppm. Production wells penetrate the Morrowan trench at depths ranging from 1,525 to 4,000 m (5,000 to 13,000 ft). The plants receive the brines through a system of pipelines. A chemical process involving a series of oxidation and reduction reactions extracts the iodine from solution. The final product, elemental iodine, is greater than 99.5 percent pure as either crystalline flake or prill.

Iofina plc lost its court case in Montana District Court in 2016 against the Montana Department of Natural Resources and Conservation. As a result, Iofina's development of the Atlantis and Triton projects in Montana is no longer feasible under its current water permit.

Iofina's five production plants in Oklahoma extract iodine from third party oil brine streams located at salt water injection sites. Oilfield brines from oil and natural gas wells in the Mississippi Lime play of southern Kansas and northern Oklahoma provide feedstock. The extraction technology utilizes small modular units that can tolerate relatively high temperatures and hydrocarbon fouling. Iofina production from its IOsorb plants in 2016 decreased by nearly 16.7 percent from 2015. Reduced salt water disposal well water by order of the Oklahoma Corporation Commission was responsible for the decrease.

Kiva Holding Inc. (KHI) reported that its trial run in 2016 at its blow-out-process plant near Leedey, OK was a success. The plant produced 64 t (70.5 t) of crystalline iodine in 2016. Projected output is 180 to 200 t/a (198 to 220 stpy). Full outcome of the lawsuit between Iofina and KHI reported here in 2016 is pending.

Consumption

The USGS reported imports for consumption of crude iodine in the United States at 5,630 t (6,206 st) in 2015 and an estimated 5 kt (5,511.6 st) in 2016. Major uses in the United States, in descending order, include X-ray contrast media (XRCM), pharmaceuticals, liquid crystal display (LCD) screens, and iodophors (water-soluble materials that release free iodine when in solution). Other uses, considered as traditional, include sanitation, animal feed, catalysts, heat stabilizers, inks and colorants, photographic chemicals, laboratory reagents, production of batteries, high-purity metals, motor fuels and lubricants and others.

Manufacturers use iodine for a myriad of intermediate iodine compounds, so determining specific end-uses is difficult. Organic iodine compounds accounted for 60 percent of domestic iodine consumption in 2016 as reported by the USGS, including ethyl and methyl iodide, ethylenediamine dihydroiodide and povidine-iodine. Inorganic iodine compounds represent 40 percent of domestic consumption including potassium iodide, which accounted for approximately 20 percent, or half. The remaining 20 percent were hydriodic acid, potassium iodate, sodium iodide and resublimed iodine.

Major uses of iodine on a worldwide basis include XRCM and LCDs along with such traditional uses as polarizing film applications, iodophors, chemicals, organics, pharmaceuticals, human nutrition and animal feed, nylon production, and others. Iodophors are used in a variety of antiseptics, biocides, and disinfectants in medical and agricultural applications. Iodine is used as an important catalyst in the production of various chemical intermediates.

Demand

Major growth drivers behind the increasing demand for iodine are its use in XRCM, LCDs, and light-emitting diodes (LEDs — two-lead semiconductor light sources). Increased use of iodine in LCDs arose from the growing demand in the quantity and size of large screen televisions. Many applications, however, are related to human and animal health and nutrition. Additional major applications include biocides, disinfectants, iodized salt, to fight iodine deficiency disease, and synthetic fabric treatments, nylon for example.

Blocking the uptake of radioactive iodine isotopes responsible for thyroid cancer is another large demand for iodine. Potassium iodide (KI) prevents such cancers and so is a staple prophylactic for residents proximal to nuclear power plants.

Demand for iodine also increased in several traditional applications such as a catalyst in the chemicals industry, particularly acetic acid production. Acetic acid is used as a solvent in terephthalic acid for use in the production of soft drink containers (polyethylene terephthalate).

Increased demand for iodine as a disinfectant and in water treatment continues to increase as developing nations expanded treatment of water supplies.

A large percent of industrial nation populations, Japan, United States and Western Europe is reaching age 65 and older. So diagnostic testing associated with health care will grow with increased demand for XRCM, which may contain up to 60 percent iodine.

Developing nations, such as China and India, represent potential markets for traditional uses. Use in veterinary antiseptics in the Asia Pacific and Latin America is another example of these potential markets. New applications also offer potential markets, such as the substitution of chlorofluorocarbons with relatively benign fluoroiodocarbons in refrigerants, aerosols, plastic foam blowing, metal and electronics cleaning, solar cell technology, and fire suppression systems.

Prices

Iodine prices surged following panic purchasing of KI tablets after the Fukushima nuclear disaster in 2011-2012. They then began declining in 2013. Overproduction, excess supply, and increased competition in the marketplace during the period 2013-2016 forced producers to increase efficiencies and reduce costs at their plants.

The price for iodine at the beginning of 2016 was

US$27.50 to $32.00 (iodine crystal, 99.5 percent min, drums, per kg; contract and spot bases) as reported by the trade journal *Industrial Minerals*. The journal reported the January 2017 spot price for iodine (crystal, 99.5 percent min, drums, per kg) delivered to the United States and Europe at $18.50 to $21; the contract price for iodine was $19.50 to $21 (crystal, 99.5 percent min, drums).

Predicting when prices will bottom out is difficult, and demand is expected to increase at a moderate pace in 2017. Markets will remain unstable until adjustments in production and supply take place, but expanded production in Iran, Russia, Turkmenistan, and the United States. may cause even lower prices. It is possible that some companies may hold the line at what price they are willing to sell, but it is unlikely to have much effect.

Substitutes

Iodine cannot be replaced in certain pharmaceuticals, catalytic uses, and human and animal nutrition. Bromine and chlorine could substitute for iodine in biocides, colorants, and inks, but they are considered inadequate in most applications. Some evidence suggests that chlorhexidine-alcohol may be more efficacious as an antiseptic than povidone-iodine. Antibiotics and boron also may substitute for iodine as biocides. One study suggests that iodine compounds applied topically as a disinfectant may actually replace some antibiotics. ■

KAOLIN

by Daniel M. Flanagan, National Minerals Information Center, U.S. Geological Survey

In 2016, U.S. kaolin production (the quantity sold or used by producers) declined by 5 percent to an estimated 5.71 Mt (6.29 million st) valued at $752 million from an estimated 5.99 Mt (6.6 million st) valued at $776 million in 2015 (Fig. 1). Sales from Georgia represented an estimated 90 percent of U.S. kaolin output, and South Carolina accounted for 6 percent, followed by, in descending order of tonnage, Alabama, Nevada, Arkansas, Florida, Texas and California. About 52 percent of all kaolin sold was water-washed, followed by airfloat, 19 percent; calcined, 14 percent; delaminated, 9 percent and unprocessed, 6 percent. Production data were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration.

World production of kaolin was an estimated 37 Mt (41 million st) in 2016, an increase of 4 percent from an estimated 35.6 Mt (39.2 million st) in 2015. The United States continued to lead in the production of refined kaolin, followed by Germany, Brazil, Turkey and Ukraine.

Consumption

Paper coating was the primary market for U.S. kaolin in 2016 and likely accounted for more than 35 percent of domestic and export sales combined. Other leading U.S. end uses of kaolin were refractories (an estimated 8 percent of total sales); miscellaneous ceramics (7 percent); fiberglass and mineral wool (6 percent); paint (5 percent); rubber (4 percent); miscellaneous fillers, extenders, and binders (4 percent); oil and gas refining catalysts (4 percent); heavy-clay products (2 percent); and paper filling (not listed in order, percentage withheld to avoid disclosing company proprietary data). A significant quantity of kaolin also was sold for production of ceramic proppants used in hydraulic fracturing, but available data were insufficient for a reliable estimate of the market size. In 2015, domestic sales for paper coating fell by an estimated 23 percent from those in 2014, continuing a pattern that began in the late 1990s (Fig. 2), and sales for miscellaneous ceramics declined by an estimated 26 percent, driven by reduced use of ceramic proppants in oil and gas drilling owing to low crude oil prices. Data for 2016 are not available,

Figure 1

Salient U.S. kaolin statistics and U.S. paper production, 1900 through 2016. Following nearly 100 years of mostly uninterrupted growth, domestic kaolin production decreased after 1998 owing primarily to declining U.S. paper markets. U.S. exports declined after 2005 as a result of increased use of calcium carbonate in paper and the 2008–2009 recession. Imports have remained fairly steady since 1900 because the United States is self-sufficient in kaolin. (Source: Food and Agriculture Organization of the United Nations, U.S. Geological Survey).

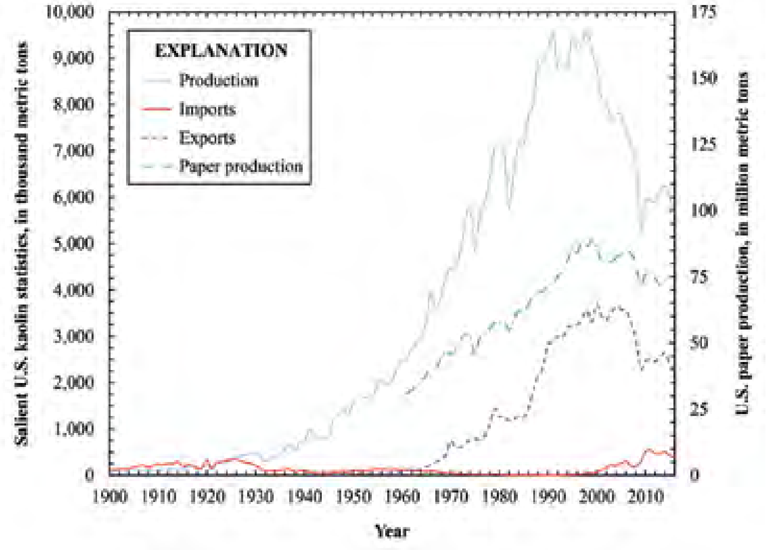
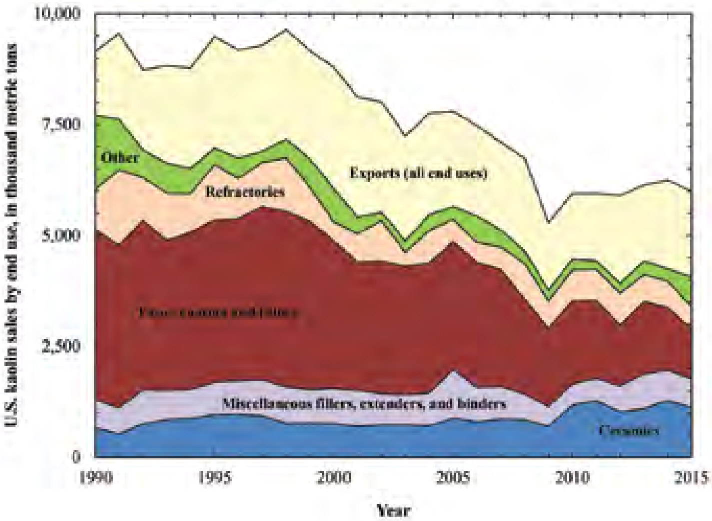


Figure 2

Domestic kaolin sales by major end use, 1990 through 2015. Sales data for 2015 are estimated.



but industry trends suggest that sales for paper and proppants continued to decline.

Prices

The average unit value of kaolin in 2016 was estimated to be \$132/t (\$120/st), a slight increase from an estimated \$130/t (\$118/st) in 2015. Unit values for individual kaolin types ranged from an estimated \$45/t (\$41/st) for unprocessed kaolin to \$160/t (\$145/st) for calcined kaolin. At the end of the year, reported prices for paper-coating grades of kaolin from a plant in Georgia ranged from \$139 to \$224/t (\$126 to \$203/st) compared with \$130 to \$209/t (\$118 to \$190/st) at year-end 2015. The average free alongside ship value of exported kaolin was \$230/t (\$209/st) in 2016, unchanged from that of 2015, and the average customs value of imported kaolin was \$112/t (\$102/st), up from \$103/t (\$93/st).

Foreign trade

Kaolin exports declined by 5 percent in 2016 to 2.29 Mt (2.52 million st) valued at \$527 million from 2.42 Mt (2.67 million st) valued at \$557 million in 2015 (Fig. 1). Japan received 17 percent of the U.S. export tonnage, followed by Mexico (15 percent), China (15 percent), Finland (7 percent), Canada (6 percent), and Taiwan (5 percent). Imports of kaolin totaled 389 kt (429,000 st) valued at \$43.6 million, a decrease of 9 percent from 426 kt (470,000 st) valued at \$43.7 million during the prior year. Nearly all of the imported kaolin (96 percent) originated in Brazil. Based on entry and departure ports, up to 154 kt (170,000 st) and 127 kt (140,000 st) of refractory kaolin may have been exported under the category for fire clay in 2015 and 2016, respectively, and some imports from Brazil were likely destined for paper plants in Canada.

Outlook

The downturn in U.S. paper production (Fig. 1), coupled with competition from calcium carbonate as a paper coating and filler, led to continued decline in sales of domestic kaolin to the U.S. paper industry since the late 1990s (Fig. 2). Exports to paper markets in Asia partially offset decreases in sales within the United States in the recent past, but papermakers in Asia are beginning to make greater use of calcium carbonate. As a result, domestic and export sales for paper applications will likely continue to decrease in coming years. The U.S. Energy Information Administration forecasts that crude oil prices will rise in 2017; sales of kaolin for ceramic proppants will likely increase as well if higher prices lead to greater oil and gas drilling activity. Based on growth in domestic construction spending over the past several years and a rise in U.S. housing starts in early 2017, kaolin sold for construction products may also increase slightly. Overall, U.S. sales of kaolin are expected to remain unchanged or fall slightly in 2017 as decreased sales for paper applications outpace gains in other markets. ■

KYANITE, ANDALUSITE AND SILLIMANITE

by William L. Lassetter, Virginia Department of Mines, Minerals and Energy

Kyanite, andalusite and sillimanite are aluminum-silicate minerals with the same chemical formula, Al_2SiO_5, but different atomic structures and physical properties, i.e. are polymorphic. Mullite is a closely related mineral with the chemical formula $Al_6Si_2O_{13}$ that occurs rarely in nature but can be synthesized from other alumina- and silica-enriched minerals using a thermal treatment process referred to as calcination. Collectively, these minerals, along with topaz ($Al_2SiO_4F_2$) and dumortierite ($Al_7(BO_3)(SiO_4)_3O_3$) belong to the sillimanite minerals group, which are valued as industrial raw materials for the manufacture of heat and acid refractories for ceramics industries, precision castings, refractory additives and fillers, and other applications in the ferrous and nonferrous foundry industries. Due to the qualities of hardness, durability and resistance to heat and chemical corrosion, exceptional specimens of the sillimanite minerals group are often marketed in the gemstone and jewelry industry.

The sillimanite minerals are common constituents in metamorphic rocks, typically making up a percent or two of the mineral composition of peraluminous gneisses and schists. Economic deposits are found in a variety of geologic settings that include massive segregations in metamorphosed aluminous sediments, as stratiform replacements within foliated and nonfoliated quartzose rocks often associated with meta-volcanic strata, mineralized quartz veins and pegmatites, and in residual soils and placers. Andalusite also occurs in hornfels and other thermally-altered pelitic rocks within contact metamorphic aureoles adjacent to intrusive stocks. In the United States, economic and subeconomic concentrations of sillimanite minerals are known to occur in the Western states of Alaska, California, Idaho, Nevada and New Mexico as well as the Appalachian regions of Georgia, North Carolina, South Carolina and Virginia. Significant occurrences of kyanite and sillimanite are found in heavy mineral sand deposits in Florida. Outside of the United States, mining and/or potentially significant resources of sillimanite minerals have been reported in Australia, Brazil, Canada, China, France, India, Kenya, Nigeria, Norway, Peru, Russia, South Africa, Ukraine and Zimbabwe.

Production

Global production figures for the sillimanite minerals are rough estimates at best. Annual production figures are often held as proprietary information by mining companies and reliable estimates of output in many producing countries are often not available. Nevertheless, the U.S. Geological Survey (USGS) estimated global production of sillimanite minerals in 2016 to be about 390 kt (430,000 st), which included 190 kt (209,000 st) of andalusite produced in South Africa, 100 kt (110,000 st) of kyanite and calcined kyanite from the United States, 65 kt (72,000 st) of combined sillimanite and kyanite from India and 35 kt (38,000 st) of andalusite from Peru. For comparison, the British Geological Survey estimated global production in 2015 to be about 526 kt (580,000 st), including combined sillimanite minerals mined in Brazil, France, India, Madagascar, Nepal, South Africa and the United States.

Kyanite Mining Corp. (KMC), a privately owned company based in Dillwyn, VA, remains the world's largest producer of industrial kyanite and calcined kyanite (mullite). The company mines kyanite-bearing quartzites associated with felsic and mafic volcanic rocks of the Chopawamsic Formation in the central Virginia Piedmont region. Of the vast resources located at Willis Mountain, kyanite generally makes up 10-40 percent of the host quartzite rock. Current surface mining operations and processing facilities are located in eastern Buckingham County near the town of Dillwyn. In the annual production report to the Virginia Department of Mines, Minerals and Energy, KMC reported about 80 kt (88,000 st) of combined kyanite and calcined kyanite in 2016. Compared to 2015 (109 kt or 120,000 st), output declined about 25 percent. KMC states the annual production capacity at the Virginia operations to be about 140 kt (154,000 st) for commercial grade kyanite concentrates (>57

Figure 1

U.S. kyanite export and global steel production.

percent Al_2O_3, <0.75 percent Fe_2O_3), and 30 kt (33,000 st) for calcined kyanite. The company markets a range of milled kyanite and mullite products that are shipped by truck and rail to a variety of domestic and international customers. Exports currently account for about one-half of KMC's business.

Elsewhere in the United States, there is only one other commercial producer of sillimanite minerals, Piedmont Minerals Division of Resco Products Inc., with operations located near Hillsborough, NC. The company mines deposits of massive pyrophyllite ($AlSi_2O_5(OH)$) containing natural mixtures of andalusite, topaz and quartz. The mineralized zones were formed in structurally controlled hydrothermally-altered metavolcanic rocks of the Carolina slate belt geologic terrane. The deposits of high-purity silica and alumina provide the materials for a range of monolithic refractories, high-alumina brick and specialty mineral products serving the foundry and ceramic industries.

The Refractory Minerals division of Imerys Group is the world's largest supplier of industrial andalusite for refractories, with major markets located in Western Europe, North America and several emerging market countries. In 2016, the company produced andalusite from mine operations located in France, China and South Africa. The Kerphalite Mine located in the Glomel region of France has been in operation since the 1960s and recovers andalusite from deeply weathered Ordovician-age schists proximal to granitic rocks of the Armorican Massif. Near Korla in the Xinjiang autonomous region, China, andalusite deposits are mined and processed at the Yilong Plant to produce "Yilongite" (55-57 percent Al_2O_3). Surface mining operations in the Transvaal region of the Republic of South Africa include the Annesley Mine near Burgersfort, Havercroft Mine near Sekhukhuneland, the Krugerspost Mine at Lydenburg and the Rhino Mine near Thabazimbi. The South African deposits were formed in pelitic rocks of the Pretoria Group within the contact metamorphic aureole of the Bushveld Igneous Complex. Imerys markets a wide variety of products under the trademarked names Durandal, Purusite, Kerphalite and Randalusite. Annual production tonnages and capacities for the individual Imerys mine sites are not readily available.

Andalusite Resources (Pty) Ltd. produces milled and run-of-mine andalusite products from surface mine operations located near Thabazimbi in Limpopo province, South Africa. The deposit is situated on strike and to the southwest of Imerys's Rhino Mine. Andalusite Resources reported annual production capacity in excess of 70 kt (77,000 st), with reserves amounting to about 100 years of mining at that annual rate. The company globally markets a range of milled products under the trade name Marlusite with average alumina content stated to be >57 percent Al_2O_3.

Extensive reserves of sillimanite with lesser amounts of kyanite are mined in the Republic of India by a combination of public and private sector operators. The Indian Bureau of Mines reported four sillimanite mines in operation during 2015-2016 located in the states of Andhra Pradesh, Odisha, Kerala and Maharashtra. Total production of sillimanite for the period was about 71 kt (78,000 st), up by about 6 percent from the output reported for 2014-2015 (66 kt or 72,000 st). About 21 percent was exported mainly to China, Nepal, Japan and Western Europe. Current estimated sillimanite resources are nearly 67 Mt (74 million st). About 3 kt (3,300 st) of kyanite were beneficiated at five mines located in Maharashtra and Karnataka during 2015-2016. The majority of the mineral produced was consumed domestically. Current kyanite resources include about 103 Mt (113 million st) of which less than 2 percent is considered medium- to high-grade.

Consumption

Iron- and steel-manufacturing industries are the principal consumers of refractories manufactured from the sillimanite minerals. These industries require high-temperature refractory linings for metallurgical furnaces and other high-performance heat and corrosion resistant materials. Refractory products include monolithics, firebrick, mortars, kiln furniture and investment casting shell molds. In the steel and foundry industries, as well as other metallurgical and glass applications requiring extreme durability, temperature, and corrosion resistance, mullite and calcined kyanite products are often used exclusively. Other important end products include glazes and chamotte for porcelain and sanitary ware, electrical insulators, heating elements, ceramic tiles, brake shoes and spark plugs.

Prices

Sales prices for imported and exported sillimanite minerals vary depending upon several factors including grade and purity, particle (mesh) size, packaging, monetary exchange rate, source and destination. Relatively weak demand for refractories during much of 2016 may have impacted sales in some regions. The Department of Mineral Resources, Republic of South Africa reported a 21.5 percent decrease in the average unit value per metric ton of andalusite sold locally between Q4 2015 (approximately $141 or $128/st) and Q1 2016 (approximately $111 or $100/st). Nevertheless, export sales unit prices reported by the periodical *Industrial Minerals* reflected relatively stable price ranges throughout the year for the most frequently traded minerals. Kyanite concentrate (55-60 percent Al_2O_3) from the United States ranged from about $248 to $353/t ($225 to $320/st), while calcined kyanite (55-60 percent Al_2O_3) ranged from about $413 to $485/t ($375 to $440/st). Andalusite FCA-mine, South Africa (57-58 percent Al_2O_3) ranged from about $262 to $317/t ($237 to $288/st). Andalusite f.o.b.-European port, France (55-59 percent Al_2O_3) ranged from $388 to $464 ($352 to $421/st). The estimated export price of sillimanite (56-60 percent Al_2O_3) f.o.b., India averaged about $110/t ($100/st).

Uses

The sillimanite minerals are valued in the manufacture of refractories and ceramic products due to their high alumina content (less than 55 percent Al_2O_3), volumetric stability at high temperatures, resistance to thermal shock, low thermal conductivity, resistance to chemical corrosion, electrical insulation capabilities, among other properties. Each of the minerals in the group is characterized by specific expansion and thermal properties when calcined to produce a mixture of mullite and residual silica. At decomposition temperatures ranging from as low as 1,250 °C (2,282 °F) for kyanite up to 1,650 °C (3,002 °F) for sillimanite the percent volume expansion is both predictable and irreversible. Calcined kyanite will expand in volume by an amount that is dependent on initial particle size. Very fine particles (325-mesh) increase volumetrically by about 2 percent, while coarser particle fractions (35-mesh) can potentially expand up to about 25 percent in volume. Calcined andalusite and sillimanite expand in volume by about 6 percent and 4 percent, respectively. Below temperatures of decomposition, the minerals are characterized by relatively low coefficients of thermal expansion.

Industry news

In late 2016, the South African Competition Tribunal rejected the proposed merger of Imerys South Africa Pty and Andalusite Resources Pty Ltd., indicating that such a merger would result in more than 80 percent of the current global supply of andalusite under the control of Imerys SA.

In northern Peru, Latin Resources Limited continued seeking joint venture partners to develop the Guadalupito andalusite project located near the port city of Chimbote. The company has reported significant resources contained in two deposits with current inferred resources of 1.3 Gt (1.4 billion st) of the combined minerals andalusite, magnetite, ilmenite, rutile, zircon, monazite, garnets and apatite. The average grade of the combined deposits is reported to be 5.7 percent heavy minerals. At the Los Conchales deposit, andalusite accounts for about 23 percent of the heavy mineral content.

There was continued interest on the part of the Russian government in the vast kyanite resources identified on the Kola Peninsula in the northern Murmansk region. The resources are concentrated in the Bolshie Keivy Mountains in 23 separate deposits, potentially accessible to surface mining operations. The preliminary estimate of the total resource indicates about 966 Mt (1.1 billion st) of ore at a depth not exceeding 100 m (328 ft), making it one of the largest kyanite occurrences in the world. The availability of this potential source of alumina would be of great interest to industrial consumers in Russia, but a major concern is the remote location and potential economic markets.

Trends and outlook

The relative strength of the steel manufacturing industry as measured by steel output has been a reliable indicator of the global demand for refractories, and thus sillimanite minerals. The World Steel Association reported global crude steel production in 2016 reached 1.6 Gt (1.8 billion st) in 66 countries, up about 0.8 percent above the previous year, but down 2.5 percent from the peak global production in 2014. Annual production increased over 2015 in Asia (up 1.6 percent), with China leading the way with 808.4 Mt (890 million st) produced. Japan was the second largest producer with about 104.8 Mt (115 million st). India produced 95.6 Mt (105 million st), up 7.4 percent over 2015, continuing a decade-long trend of steady positive growth in steel manufacturing capacity that could signal market opportunities for refractories. Steel production in the European Union countries totaled 162.3 Mt (178 million st), down about 2.3 percent for the region compared to 2015. Total steel output in North America was 111 Mt (122 million st); the United States was the leading producer with 78.6 Mt (86.6 million st), down 0.3 percent from 2015. Looking forward to 2017 and beyond, the outlook for the global steel industry is cautiously positive with annual growth in the 1-2 percent range. From a regional perspective, positive demand for refractories is likely to continue in Asia and North America, but notable growth opportunities may be found in emerging and developing economies in Brazil India and Russia.

The demand for high-quality raw and calcined sillimanite minerals is closely linked to the need for high-performance refractories with superior operational life spans in increasingly automated and high-tech industry settings. If the developed economies continue along the present pathway toward full recovery from the global financial crisis that began in 2008, opportunities are likely to abound for expanding refractory markets, especially in the steel production, construction and infrastructure development sectors. Geopolitical uncertainties, rising nationalism and retreating globalization, energy costs, currency volatilities and the impacts on capital flow all present potential economic headwinds. ■

LITHIUM

by B.W. Jaskula, National Minerals Information Center, U.S. Geological Survey

In 2016, estimated world lithium production was about 35 kt (39,000 st) of lithium recovered from minerals and brines, a 22 percent increase from that of 2015. Estimated world lithium consumption was about 34 kt (38,000 st) of lithium contained in minerals and compounds, a 14 percent increase from that of 2015. Estimated U.S. consumption was about 1.8 kt (2,000 st) of contained lithium. The United States was thought to rank fourth in global consumption of lithium but was the leading producer of value-added lithium materials. One company, Albemarle Corp., produced lithium compounds from domestic brine resources near Silver Peak, NV.

Worldwide lithium production capacity was reported to be 44.8 kt (49,400 st) in 2015; capacity utilization was estimated to be 64 percent in 2015 and 71 percent in 2016. Despite available capacity, spot lithium carbonate prices in China in 2016 increased up to 300 percent, briefly exceeding $27,500/t ($25,000/st), based on an acute, but likely temporary, shortage of imported spodumene from Australia. The rest of the world experienced more modest spot price increases owing to utilization from more diversified sources of lithium.

U.S. imports of lithium compounds in 2016 were 15.2 kt (16,800 st) (gross weight), an increase of 13 percent from those of 2015. Import sources of lithium chemicals were Argentina, 63 percent; Chile, 33 percent and others, 4 percent. Exports of lithium compounds from the United States were 8.2 kt (9,100 st), a decrease of 15 percent from those of 2015. About 72 percent of all U.S. exports of lithium compounds went to Germany and Japan, which received 1.5 kt and 4.4 kt (1,660 and 4,920 st), respectively. The remainder was divided among many other countries.

The two dominant sources of lithium are brines and hard rock mineral concentrates. Essentially the same lithium compounds can be produced from either type of deposit. However, owing to typically lower production costs, brines became the principal source for lithium compound production at the end of the 1990s. During the last several years, however, due to growing lithium mineral concentrate demand from China's chemical companies (where the concentrate is converted to battery-grade lithium carbonate and lithium hydroxide), mineral-sourced lithium has regained market share and was estimated to account for one-half of the world's lithium supply in 2016. Globally, ceramic and glass applications also use mineral concentrate feed. The lithium content of the minerals added to the ceramics and glass melt reduces their melting temperature and viscosity and increases their resistance to thermal shock; other constituents of the concentrates provide other important glass components. Potential additional sources of lithium include geothermal brines, hectorite clay, jadarite and oilfield brines.

Chile has been a global leader in the production of lithium carbonate since 1997, the year that it surpassed the United States. Albemarle Corp. and Sociedad Química y Minera de Chile S.A. (SQM) operated lithium brine facilities on the Salar de Atacama in the Andes Mountains. Albemarle produced lithium carbonate and lithium chloride, and SQM produced lithium carbonate and lithium hydroxide at plants in Antofagasta.

In Argentina, FMC Corp. produced lithium carbonate and lithium chloride from brines from the Salar de Hombre Muerto in the Andes Mountains, and, in 2015, Orocobre Ltd began commercial lithium carbonate production from its brine operation at the Salar de Olaroz in Jujuy Province. In China, lithium compounds were produced at two brine operations and from lithium minerals. China was the only country producing lithium carbonate and lithium hydroxide from domestic and imported lithium minerals. Australia's Talison Minerals [jointly owned by China's Chengdu Tianqi Industry (Group) Co., Ltd. and Albemarle Corp.] was the leading producer of lithium concentrates, and, in 2016, led the world in lithium production. Brazil, Portugal and Zimbabwe also produced significant quantities of lithium concentrates.

The past year has seen much activity in the lithium industry. Albemarle received government approval to increase its brine extraction from the Salar de Atacama. Albemarle, FMC and SQM each announced plans to further expand lithium hydroxide production capacity to meet increasing demand from the electric vehicle industry. Albemarle and Chengdu Tianqi announced plans to increase capacity of Talison's spodumene operation, and Chengdu Tianqi began construction of a lithium hydroxide plant in Australia. To diversify supply, Albermarle and SQM each announced planned joint ventures with companies in Argentina. Two additional Australian spodumene operations, one new and one inactive since 2013, planned to begin commercial concentrate production in early 2017.

Lithium resource exploration in the United States has increased significantly in recent years in anticipation of increasing demand for lithium-ion batteries and the recent rise in lithium prices. Approximately 30 mining claims (mostly in Nevada) were in the early exploration stage by junior mining companies.

Albemarle and FMC are the world's leading producers of downstream lithium chemicals, with U.S. operations in Bessemer City, NC, Kings Mountain, NC and New Johnsonville, TN. Their downstream lithium chemicals are typically derived from lithium carbonate, lithium chloride and lithium hydroxide, most of which are imported from Argentina and Chile.

Estimated global distribution for lithium used in 2016 was: batteries, 43 percent; ceramics and glass, 28 percent; lubricating greases, 7 percent; polymer production, 5 percent; continuous casting mold flux powders, 4 percent; air treatment, 2 percent; and other uses, 11 percent. Lithium's important properties include low density, high specific heat, low coefficient of thermal expansion, high electrochemical potential and excellent thermal conductivity.

Lithium-ion batteries have rapidly gained importance because they are used extensively in portable electronic devices and are being used increasingly in portable electric tools, hybrid-electric vehicles (HEVs), plug-in hybrid-electric vehicles (PHEVs), electric vehicles (EVs), and grid storage applications.

Increased use of lithium-ion batteries in HEVs, PHEVs and EVs could create high demand for lithium chemicals in the near future.

Lithium supply security has become a top priority for technology companies in the United States and Asia. Strategic alliances and joint ventures between technology companies and exploration companies have been, and are continuing to be, established to ensure a reliable, diversified supply of lithium for battery suppliers and vehicle manufacturers. Because lithium carbonate is one of the lowest-cost components of a lithium-ion battery, the concern was not supplier cost differences or production efficiency but supply security attained by acquiring lithium from diversified sources.

Substitutes for lithium compounds and metal are possible in glass, ceramics, greases, and batteries. Examples are sodic and potassic fluxes in ceramics and glass manufacture; calcium and aluminum soaps as substitutes for stearates in greases; and calcium, magnesium, mercury and zinc as anode material in primary batteries. Lithium is preferred to these potential substitutes, however, because lithium's physical and chemical properties make it the superior material for most of its applications. ■

MAGNESIA/MAGNESITE

by Mark Wajer, MagApps LLC

Synthetic deadburned magnesia (DBM) is produced in the United States only by Martin Marietta Magnesia Specialties from brine and dolomitic lime at its Manistee, MI facility. There are no U.S. producers of fused magnesia (FM). Refractory for steel production is the principal use for both DBM and FM. Domestic steel production was flat at 81 t (89 st) as compared to last year. The imports of DBM and FM totaled 149 kt (164,000 st) in 2016 of which 67 percent was from China, 11 percent from Brazil and 9 percent from Turkey. Compared to 2015, import volume was unexpectedly 42 percent lower which could be the result of anticipation of lower prices in 2017 due to the elimination of Chinese export tariffs of 10 percent and export quotas. Pricing of the Chinese imports continued to drop. They averaged $496/t ($449/st) in 2016 compared to $558/t ($506/st) in the previous year and $645/t ($585/st) in 2014. Exports totaled 31.5 kt (34,700 st) in 2015 with South Africa (50 percent) and Canada (30 percent) as the principal destinations. There is a small amount of DBM used in specialty ceramics and glass, magnesium phosphate cements and friction materials. FM has higher purity, larger crystals and higher density than DBM providing longer life as a refractory. Some of the decline in DBM imports may also be partially attributed to the increased use of longer lasting FM. FM is also used in electrical heating elements due to its unique property of being an electrical insulator but a heat conductor. In 2016, China posted a new record for FM exports worldwide. RHI AG of Austria announced plans to acquire at least 46 percent of Magnesita SA of Brazil in 2017. Both companies are major producers of DBM and FM and other refractory materials.

Reactive grade magnesia has a variety of uses including the manufacture of magnesium salts, environmental applications, fertilizer, rubber and plastics, leather tanning, magnesia-based cements, glass, hydrometallurgy, etc. Animal feed is the largest single application. Martin Marietta Magnesia Specialties is the only synthetic U.S. producer of lightburned magnesia (LBM). Premier Magnesia has a caustic calcined magnesite (CCM) facility in Gabbs, NV where it mines natural magnesite. LBM usually has a higher purity than CCM. However, CCM and LBM are used in many of the same applications where purity is not a critical property so they are both included under CCM source data. Domestic CCM/LBM production remained flat at about 156 kt (172,000 st) with an average sales price (ASP) of about $380/t ($344/st). In 2016, imports totaled 157 kt (173,000 st) with 61 percent from China, 23 percent from Canada and 9 percent from Australia. Imports were down 14 percent in 2016 compared to previous year. Average CCM import value was $277/t ($251/st) in 2016 down 6 percent over the previous year. The majority of imports were CCM for animal feed. Chinese CCM prices declined 10 percent in 2016. China also eliminated the export quota and export tariff of 5 percent on their CCM in 2017. Exports grew 39 percent to 8.1 kt (8,900 st) with an ASP of $679/t ($616/st). LBM commands a higher price due to its higher purity and other critical properties. Estimated reactive grade magnesia consumption in 2016 was 313 kt (345,000 st).

The third major magnesia compound is magnesium hydroxide (MDH) derived from brucite, slaking CCM or synthetically produced from seawater or brine. Synthetic producers include SPI Pharma (Lewes, DE), Tetra Technologies (El Dorado, AR) and Martin Marietta Magnesia Specialties (Manistee, MI). Slaking producers include Premier Magnesia (Gabbs, NV), Inland Environmental Resources (Pasco, WA) and PolyTec (North Little Rock, AR). Garrison Minerals (Denver, CO) employs multiple processes. Most of the MDH is supplied as a slurry for use in water treatment, flue gas emissions, pulp bleaching and the production of magnesium salts. MDH is increasingly replacing caustic soda as a safe alternative. About 20 percent of the total MDH volume is sold as a powder for use in pharmaceuticals, flame retardants and magnesium compounds. Total U.S. production is approximately 185 kt (204,000 st) at an average value of $473/t ($429/st). There is nearly a tenfold difference in prices for the different hydroxide grades. In 2016, exports, mostly as an aqueous slurry, totaled 21.6 kt (23,800 st) with Canada at 50 percent, Sweden at 16 percent and Mexico at 7 percent as the major destinations. Exports with an ASP of $805/t ($730/st) were up 20 percent compared to 2015. MDH is the most widely distributed magnesium product with shipments to 53 countries. Imports were up 20 percent to 7.8 kt (8,600 st) with an average value of $1,671/t ($1,515/st). Imports of Mexican MDH with an ASP of $773/t ($701/st) grew to a 48 percent share in 2016 from 45 percent last year. Israel at 18 percent and Netherlands at 13 percent were the other primary importers. Huber Engineered Materials of Atlanta, GA completed the purchase of Ablemarle's Martinswerk chemical business that includes 50 percent ownership of Magnifin in Austria. Magnifin produces specialty flame retardant grades of magnesium hydroxide from the Aman process using serpentine as the starting material. ■

MICA

by S.M. Jasinski, National Minerals Information Center, U.S. Geological Survey

In 2016, U.S. mine production of scrap and flake mica was estimated to have been 30.2 kt (33,300 st), which was down from 32.6 kt (36,000 st) in 2015. Production of ground mica also was estimated to have been lower at 49.9 kt (55,000 st) compared with 53.7 kt (59,200 st) in 2015. Mica was mined in Georgia, North Carolina, South Dakota and Virginia. Scrap mica was recovered primarily from mica and sericite schist and as a byproduct from feldspar, industrial sand beneficiation and kaolin. Ground mica was produced from domestic and imported scrap and flake mica. A small amount of sheet mica was produced as a byproduct of feldspar mining in North Carolina. In 2016, world production of scrap and flake mica was estimated to have remained unchanged from that of 2015 at 1.13 Mt (1.24 million st). China, Russia and the United States were the leading producers, by quantity. Production of sheet mica was estimated to have been 3.3 kt (3,600 st), the same as that in 2015. India and Russia were the leading producers. Consumption of all forms of scrap and flake mica was estimated to be 58.3 kt (64,200 st), slightly lower than that of 2015. Increased imports and lower exports offset the drop in production. Consumption of sheet mica was estimated to have increased by 14 percent to 1.25 kt (1,370 st) in 2016.

Mica's value is based on several of its unique physical properties. The crystalline structure of mica forms layers that can be split or delaminated into thin sheets. These sheets are chemically inert, dielectric, elastic, flexible, hydrophilic, insulating, lightweight, platy, reflective, refractive, resilient and range in opacity from transparent to opaque. Mica is stable when exposed to electricity, light, moisture and extreme temperatures. The mica group represents 37 phyllosilicate minerals that have a layered or platy texture. The commercially important micas are muscovite and phlogopite, which are used in a variety of applications. Muscovite is the principal mica used by the electrical industry to make mica-based capacitors that can operate in environments with temperatures and (or) frequencies that are too high for polypropylene capacitors. Phlogopite mica is used in plastic composites for automotive applications because of its dimensional stability, increased stiffness, and improved heat distortion temperature.

The leading domestic use of ground mica is in joint compound for filling and finishing seams and blemishes in gypsum wallboard (drywall). The mica acts as a filler and extender, provides smooth consistency, improves the workability of the compound, and provides resistance to cracking.

The second-leading use of ground mica is as an additive to drilling muds by the well-drilling industry. Coarsely ground mica flakes help prevent the loss of circulation by sealing porous sections of the drill hole. Mica is used in paint, where ground mica is used as a pigment extender that also facilitates suspension, reduces chalking, prevents shrinking and shearing of the paint film, increases resistance of the paint film to water penetration and weathering, and brightens the tone of colored pigments.

The plastics industry uses ground mica as an extender and filler, especially in parts for automobiles as lightweight insulation to suppress sound and vibration. Other significant uses for ground mica are in the rubber industry as an inert filler and mold-release compound. As a surface coating in the production of rolled roofing and asphalt shingles, mica prevents the sticking of adjacent surfaces. Mica is used in decorative coatings on wallpaper, concrete, stucco and tile surfaces. Ground phlogopite mica is used in automotive brake linings and clutch plates to reduce noise and vibration (asbestos substitute). Wet-ground mica, which retains the brilliancy of its cleavage faces, is used primarily in pearlescent paints by the automotive industry. In the cosmetics industry, its reflective and refractive properties make mica an important ingredient in blushes, eyeliner, eyeshadow, foundation, hair and body glitter, lipstick, lip gloss, mascara, moisturizing lotions, and nail polish. Mica is added to latex balloons to provide a colored shiny surface.

Muscovite and phlogopite splittings are fabricated into various built-up mica products by mechanized or hand setting of overlapping splittings and alternate layers of binders and splitting. Built-up mica is used primarily as an electrical insulation material. Mica insulation is used in high-temperature and fire-resistant power cable in aluminum plants, blast furnaces, critical wiring circuits (for example, defense systems, fire and security alarm systems and surveillance systems), heaters and boilers, lumber kilns, metal smelters, and tanks and furnace wiring. Built up mica is also fabricated into tubes and rings for insulation in armatures, motor starters and transformers.

Sheet mica is used principally in the electronics and electrical industries. Its usefulness in these applications is derived from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, stamped and machined to close tolerances.

Outlook

The major markets for ground mica — drywall joint compounds and paints — are mature and relatively stable, with growth tied to housing construction and interest rates. Demand is affected by automobile production because interior and exterior parts typically contain dry-ground mica or engineered mica composites, and exterior surfaces may be painted with wet-ground pearlescent pigments and mica-containing coatings.

Demand for ground mica in smaller specialty markets such as coated micas, cosmetics, nylon and polyester resins and polypropylene composites, is expected to have an annual growth rate slightly higher than that of the entire ground mica industry.

Consumption of block mica is expected to increase slowly by about 1 percent per year as demand increases in a few specialty markets, such as electronics. A shortage of domestic high-quality block mica is expected to continue because of the generally low percentage of high-quality mica in deposits currently being mined, mostly from pegmatites. Future supplies of mica are expected to come increasingly from imports, primarily from Brazil, Canada, China, India and Finland. ■

NITROGEN-AMMONIA

by L.E. Apodaca, National Minerals Information Center, U.S. Geological Survey

Ammonia was produced in the United States by 13 companies at 31 plants in 15 states during 2016. About 60 percent of total U.S. ammonia production capacity was based in Louisiana, Oklahoma and Texas because of those states' large reserves of natural gas, the dominant domestic feedstock for ammonia production. In 2016, U.S. producers operated at about 80 percent of their rated capacity (excluding plants that were idle for the entire year). Four companies — CF Industries Holdings, Inc.; PCS Nitrogen, Inc.; Koch Nitrogen Co. and Agrium, Inc., in descending order — accounted for 76 percent of the total U.S. ammonia production capacity.

U.S. production was estimated to be 9.8 Mt (10.8 million st) of nitrogen (N) content in 2016, slightly higher than that in 2015. Apparent consumption was estimated to have decreased slightly from 13.7 Mt (15.1 million st) of N content in 2015 to 13.4 Mt (14.7 million st) of N content in 2016. The United States was the world's fourth-ranked ammonia producer, after China, Russia and India, and the world's second-ranked consumer after China. Urea, ammonium nitrate, ammonium phosphates, nitric acid and ammonium sulfate were the major derivatives of ammonia produced in the United States, in descending order of tonnage.

Approximately 88 percent of apparent domestic ammonia consumption was for fertilizer use, including anhydrous ammonia for direct application, urea, ammonium nitrates, ammonium phosphates and other nitrogen compounds. Ammonia also was used to produce plastics, synthetic fibers and resins, explosives and numerous other chemical compounds. Imports of ammonia (N content) decreased by 11 percent, from 4.32 Mt (4.76 million st) in 2014 to 3.84 Mt (4.23 million st) in 2016. Trinidad and Tobago (67 percent) and Canada (27 percent) were the leading sources of U.S. ammonia imports. U.S. ammonia exports doubled to 182 kt (200,000 st) of N content from 2015 to 2016. Ammonia exports were primarily shipped to Morocco (52 percent), and Mexico (27 percent).

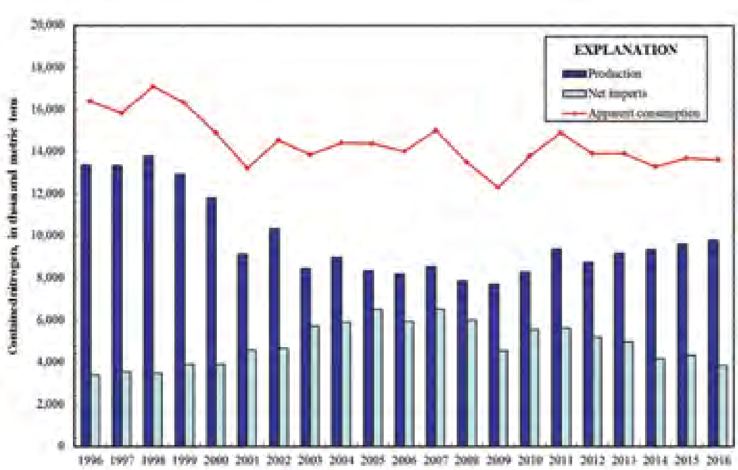
U.S. Gulf Coast ammonia prices in 2016 averaged $294/t ($267/st), 44 percent lower than the average in 2015. The Gulf Coast ammonia price was $462/t ($420/st) at the beginning of 2016 and decreased to $270/t ($245/st) by yearend.

Natural gas is often used as the feedstock to produce ammonia fertilizers, and the cost of natural gas can account for 70 to 90 percent of the production costs. The Henry Hub spot natural gas price ranged between $1.49 and $3.76/million Btu for most of the year, with an average of $2.49/million Btu. The U.S. Department of Energy, Energy Information Administration, projected that Henry Hub natural gas spot prices would average $3.12/million Btu in 2017.

A long period of stable and low natural gas prices in the United States has made it economic for companies to upgrade existing ammonia plants and plan for the construction of new nitrogen projects. During the next four years, it is expected that a total of about 3 Mt (3.3 million st) of annual production capacity will be added in the United States. The additional capacity will reduce, but likely not eliminate, nitrogen imports (Fig. 1). Global ammonia capacity is expected to increase by 10 percent during the next four years. Capacity additions are expected in Africa, Asia (except East Asia) and Eastern Europe.

Figure 1

U.S. supply and consumption of ammonia, 1996-2016.



For the first time in a decade, capacity in East Asia is not expected to increase, a result of China removing small- to medium-size nitrogen facilities and canceling planned nitrogen projects.

According to 10-year projections (2016–2026) by the U.S. Department of Agriculture, projected plantings for the eight major field crops (barley, corn, oats, rice, sorghum, soybeans, upland cotton and wheat) in the United States were expected to decrease by 4 percent by 2026. Corn production accounts for about one-half of U.S. fertilizer use and planting fewer crops affects the demand for nitrogen fertilizers. During the last eight years of the 10-year projection period, plantings were expected to remain near 100 Mha (274 million acres) compared with 104 Mha (257 million acres) in 2014. Corn, soybeans and wheat were expected to account for about 90 percent of acreage utilization for the eight major field crops. Overall corn acreage in the United States was expected to decrease by about 9 percent through the projection period. Although planted corn acreage is likely to decline, corn yields are expected to remain high, with corn being used more for feed and residual use and less for ethanol production. ■

PEAT

by L.E. Apodaca, National Minerals Information Center, U.S. Geological Survey

In 2016, domestic production of peat, excluding Alaska, was estimated to be 460 kt (507,000 st), compared with 455 kt (501,000 st) in 2015 (Fig. 1). In 2016, imports decreased slightly to 1,130 t (1,245 st) compared with 1,150 t (1,267 st) in 2015 (Fig. 1), and exports increased to 31 kt (34,000 st) in 2016 compared with 28 kt (31,000 st) in 2015. U.S. apparent consumption for 2016 decreased by 4 percent compared with that of 2015. World production was estimated to be about 28 Mt (31 million st) in 2016, which was slightly less than that of 2015.

Peat is a natural organic material of botanical origin. Peatlands are situated predominately in the shallow wetland areas of the Northern Hemisphere. Commercial deposits are formed from the incomplete decomposition of plant matter under anaerobic conditions and a gradual accumulation of peat over about a 5,000-year period. In 2016, peat was harvested in 11 states, with Florida and Minnesota being the leading producing states. Reed-sedge comprised almost 85 percent of the peat harvested in the United States, followed by sphagnum peat, with 12 percent.

At least 60 percent of all peat used in the United States was imported from Canada, which has extensive deposits of high-quality sphagnum peat. Deposits of sphagnum peat in the United States occur primarily in the northern states, with active operations in Alaska, Maine, Michigan, Minnesota, Montana, Pennsylvania and Washington. Because of its more fibrous composition, sphagnum peat is preferred for custom soil mixes and for sale to retail consumers. Sphagnum peat also is used as a filtration medium and as an absorbent. More decomposed types of peat, such as reed-sedge or humus, are used primarily in bulk by commercial landscapers and on golf courses.

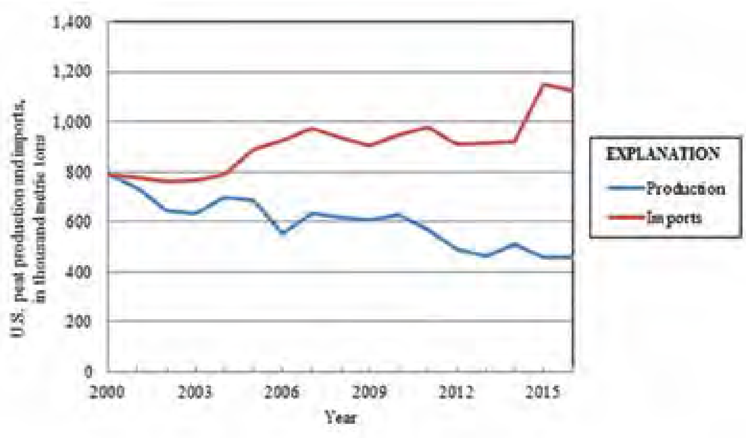
Demand for peat generally follows that of horticultural applications. General soil improvement, nurseries and potting soil mixes were the leading domestic end-use categories, accounting for about 94 percent of domestic peat sales, according to the annual U.S. Geological Survey canvass of producers. Data for the end-use distribution of peat imported from Canada were unavailable, but the imported peat was sold both in bulk for soil blending and packaged for direct horticultural use. Packaged peat, regardless of origin, commanded a higher price than bulk sales.

The number of peat producers in the United States has stabilized after falling gradually during the 1990s, when more stringent federal, state and local wetland protection regulations were enacted. The permitting procedures for new peat operations have become increasingly time-consuming and expensive, causing some companies to abandon harvesting and reducing the number of new fens and bogs brought into production. In addition, extensive areas of peatlands are located in protected wetlands, parks or other natural areas that restrict commercial development.

Peatlands also are used for agriculture, forestry, recreation and wildlife management. Factors such

Figure 1

U.S. production and imports of peat, 2000-2016.



as the growing interest in gardening, golf course development and landscaping related to residential use indicate that peat usage is likely to remain near current levels for the next several years. However, U.S. producers face increasing competition from imports of peat from Canada and alternative soil amendments, such as composted organic waste, coir (coconut fiber) and wood byproducts (for example, wood fiber and composted bark). The availability of alternative soil amendments as substitutes for peat will determine the future use of peat in different parts of the world.

Peatlands have been identified as carbon sinks, storing more carbon per hectare than any other ecosystem. Preservation and restoration of peatlands may become a high priority in the efforts to reduce greenhouse gas emissions, further restricting its availability for commercial use in future years. Peatland restoration efforts are increasing in Europe and North America. ■

PERLITE

by Bowen Li, Michigan Technological University

Perlite is an amorphous volcanic rock that mainly consists of silica with a high content of water molecules. The typical chemical composition of perlite is (wt percent): SiO_2 70-75 percent, Al_2O_3 12-15 percent, Na_2O 3-5 percent, K_2O 3-5 percent and H_2O 3-5 percent. Once it is quickly heated to high temperatures of about 900 °C (1,700 °F), the crude perlite rock expands like popcorn due to the trapped water being vaporized, which makes perlite into a lightweight and porous product (named as expanded perlite).

According to the U.S. Geological Survey (USGS), the estimated domestic production of crude perlite in the United States in 2016 was 429 kt (473,000 st), which equaled an increase of 12.7 kt (14,000 st) or 3 percent compared with 2015, and a 14.3 percent increase from 2010 (Fig.1). The imports of perlite were slightly up to 145 kt (160,000 st), a 4.5 kt (5,000 st) or a 3.2 percent increase compared with 2015, but still lower than that in 2010, 2011, 2013 and 2014. The exports of perlite rose to 43.5 kt (48,000 st) from 36.2 kt (40,000 st) in 2015, a 20 percent increase and close to the levels in 2013 and 2014. The estimated domestic consumption of crude perlite in 2016 was 440 kt (485,000 st), a 15.5 percent decrease from 2015. This is the smallest volume of consumption since 2010. Over the past 10 years, the production and exports of perlite gradually and continuously increased, while the apparent consumption was stable. The imports indicated a tendency to gradually decrease, as Fig. 1 shows.

In 2016, crude perlite ores were produced in the United States from seven mines operated by six companies in five states. As in 2015, New Mexico continualy to be the major producing state. The average price for crude perlite ore was continually raised since 2012, and estimated to be $68/t ($61/st) in 2016. This was a 1.7 percent increase from 2015, and a 17.3 percent increase from 2010. During last 10 years, the unit price of crude perlite continuously increased as Fig. 2 shows. The annual sales value of domestic crude perlite product was estimated at US$28.9 million.

There were 46 plants in 28 states that produced expanded perlite in the United States in 2016. This was a decline of 13 plants compared with 2015.

Many commercial applications of perlite have been developed in past decades. The major applications of perlite are in its expanded form. The application markets in the United States were still in building construction (such as insulation,

Figure 1

U.S. production, trade and apparent consumption of crude perlite. (Data for 2016 estimated by USGS.)

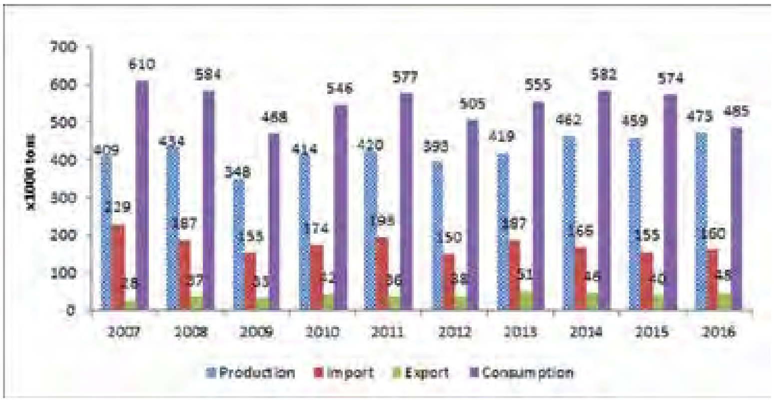
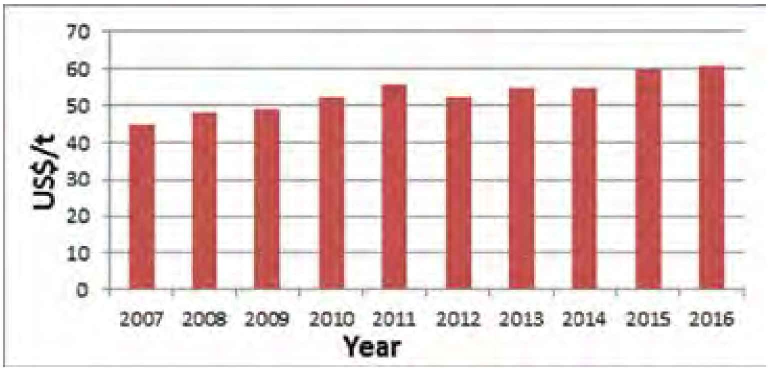


Figure 2

Unit price change of crude perlite in the United States since 2007 (Data Sources: USGS Mineral Commodity Summaries; Price in 2016 is estimated).



lightweight plasters, aggregates, and ceiling tiles) as it is lightweight and fire retardant, which accounted for 53 percent of the total consumption (Fig. 3). Other applications include fillers (15 percent), horticulture (15 percent), filter aid (9 percent) and 8 percent for miscellaneous uses, such as soil amendment, foundry, bioremediation, and explosive additive. Research of expanded perlite in new applications such as photo-catalyst, energy arresting materials, perlite-epoxy composite, perlite geopolymer, toothpaste fillers has been recently reported.

The worldwide reserve of perlite is estimated at more than 1.5 Gt (1.7 billion st). There are more than 34 deposits of perlite that have been explored in China, with an estimated 900 Mt (1 billion st) of perlite reserves. Other major countries with perlite reserves include Turkey (52 Mt or 57 million st), United States (45 Mt or 50 million st), Greece (45 Mt or 50 million st), Hungary (25 Mt or 28 million st). India reported (2016) 2.2 Mt (2.41 million st) of perlite reserve, as only one perlite deposit was found in the country. Many other countries including Japan, Russia, Germany, the United Kingdom, France, Spain, Australia, New Zealand, Indonesia, Malaysia, Iran, Brazil, Mexico, Nigeria, Zimbabwe and South Africa have reported perlite deposits, but no specific data are available.

China was the largest producer and consumer of both crude and expanded perlite in the world. Turkey and Greece were the second and third largest producers of crude perlite and expanded perlite in the world. The United States was the fourth largest producer but may be the second largest consumer worldwide.

According to a report from China Perlite Association, China has established a capacity to produce 2.7 Mt (3 million st) of crude perlite, and 100 million m^3 (131 million cu yd) of expanded perlite. In 2015, there were more than 150 producers of crude perlite and expanded perlite in the country, including more than 30 mining companies and more than 100 expanded perlite plants. However, there is no updated data for 2016. In China, 80 percent of expanded perlite was used as insulation, and the remaining 20 percent was used for other industries. In 2013, China produced 1.6 Mt (1.8 million st) of crude perlite and 19.54 million m^3 (26 million cu yd) of expanded perlite, with total sales of perlite at US$890 million, and annual consumption of expanded perlite at 19.65 m^3 (26 million cu yd) It was estimated that China had a similar or slightly higher level of production and consumption in 2016.

As Table 1 shows, other major countries producing crude and expanded perlite in 2016 include Greece (1 Mt or 1.1 million st), Turkey (901 kt of 1 million st), Iran (54 kt or 60,000 st), and Hungary (36 kt or 40,000 st). There are no production data from the traditional producers of perlite such as Japan, Italy, Russia, Mexico, Georgia, Slovakia, Australia, New Zealand, Philippines, Indonesia, South Africa and Zimbabwe.

Construction and agriculture were among the major application areas of perlite in the world. In the next few years, strong demand in the construction sector will be a major factor driving the market growth of expanded perlite, especially in green roofs and thermal insulation units (such as concrete additives, cement mixture, masonry, boulders, and bricks). Water filtration and horticulture will significantly enhance the global market of expanded perlite. According to Global Market Insights, Inc, the global market size of expanded perlite was valued at US$710.4 billion in 2015. A compound annual growth rate of 7.3 percent is expected over the coming seven years.

For specific applications, diatomite, pumice, expanded clay and shale and vermiculite can be used as asubstitute for expanded perlite. ■

Figure 3

Applications of expanded perlite in the United States.

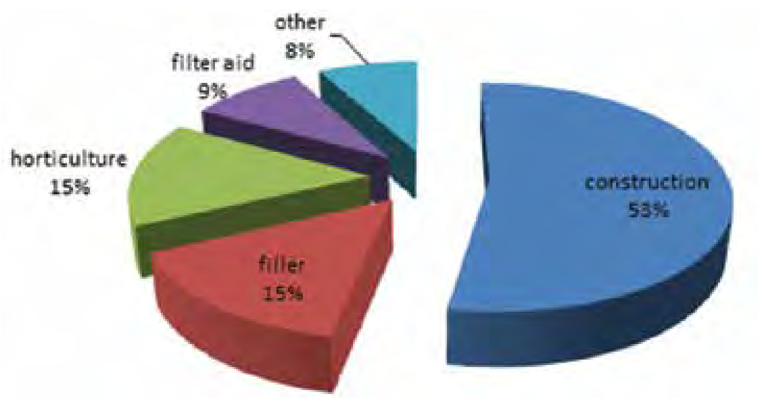


Table 1

Estimated world perlite production in 2016 (kt).

	2015	2016	%
China	1,800	1,800	39.36
Greece	1,000	1,100	24.05
Turkey	925	1,000	21.87
United States	459	473	10.34
Iran	60	60	1.31
Hungary	40	40	0.87
Mexico	26	30	0.66
Other countries	70	70	1.53
World total	4,294	4,573	100.00

*Production data from USGS, except China. (2015 data are estimated.)

PHOSPHATE ROCK

by T.M. "Mike" Gurr P.G., Gurr Professional Services, Inc.

For year 2016, Florida and North Carolina phosphate rock production accounted for 75 percent of the total U.S. production, with the balance being produced in the western states of Idaho and Utah. The Florida and North Carolina share of U.S. production is down from the 80 percent reported in 2015. U.S. production of 26.3 Mt (30.1 million st) in year 2016 was produced by five companies at 10 mines in four states and accounted for about 10.46 percent of the world production of 261 Mt (287.7 million st) for calendar year 2016 (Table 2).

In 2016, U.S. phosphate production decreased slightly by 100 kt (110,000 st), while companies increased stocks of phosphate rock marginally by 500 kt (550,000 st). The domestic production for 2016 of 27.3 Mt (30.1 million st) represented 83.2 percent of the domestic production capacity of 32.8 Mt (36.2 million st).

China's production has steadily increased from its modest production capabilities in 1970 until rapid expansion and growth began in 2005 (Fig. 1). For the past two years, China's official reported production of phosphate rock has shown substantial increases from 120 Mt (132.3 million st) for calendar year 2015 to 138 Mt (152.1 million st) for calendar year 2016. However, the U.S. Geological Survey (USGS) reports that fertilizer associations and other industry analysis have reported that the Chinese phosphate production may have been only 85 Mt (93.7 million st) in 2015 rather than 120 Mt (132.3 million st). At present, China produces more than 53 percent of the world's total production of phosphate rock. Morocco production has remained steady at 30 Mt/a (33.1 million stpy) for the past two years, which is approximately 11.5 percent of the world's production. In calendar year 2016, the U.S. phosphate rock production was 27.8 Mt (30.6 million st), which is only 10.65 percent of the world's production of phosphate rock (Fig. 1).

Imports/exports

There were no reported U.S. exports of phosphate rock in crop year 2016; nor have there been any reported exports of phosphate rock since crop year 2004. U.S. producers continue to prefer to export the higher value fertilizer products, such as monoammonium phosphate (MAP), diammonium phosphate (DAP) and triple super phosphate (TSP), in preference to phosphate rock. Approximately one-half of the MAP, DAP and TSP produced in calendar year 2016 were exported.

Importation of phosphate rock in crop year 2016 is estimated by the USGS at 1.72 Mt (1.9 million st) and for calendar year 2016 imports are estimated at 1.6 Mt (1.8 million st). Imports were from Morocco and Peru.

Uses

The manufacturing of fertilizers and the production of animal feed supplements account for more than 95 percent of phosphate rock consumption. The remainder of the production was used to produce elemental phosphorus, defluorinated phosphate rock or was used for direct application to the soil. Major fertilizers include DAP, MAP and TSP. The balance is used in a variety of products, such as vitamins, pharmaceuticals, soft drinks, toothpaste, flame retardants, glass, photographic film and other consumer goods. Continued growth of the world population and the need for dependable food supplies underscore the need for phosphate fertilizers.

Synthetic equivalents

There is no natural or synthetic substitute for phosphorus, which is essential for life in all growing

Table 1

Phosphate rock production.

Crop Year	Production (Marketable, Beneficiated)[1]				Consumption	
	Phosphate Rock Tons[2]	%BPL	Value (f.o.b. Mine)[1]	Ending stocks tons[2]	Tons[2]	Value[1]
2006	32.6	63.2	$30.24	7.45	34.5	$30.04
2007	29.7	62.4	$39.33	6.10	33.0	$39.59
2008	30.3	61.3	$84.07	4.89	34.2	$80.00
2009	27.8	62.6	$111.09	8.89	26.8	$116.75
2010	26.7	62.5	$64.53	7.57	30.1	$64.78
2011	26.5	63.4	$93.72	5.37	30.6	$92.31
2012	28.8	63.1	$98.36	5.60	31.3	$100.51
2013	31.9	62.6	$99.58	7.14	30.9	$95.51
2014	28.0	62.0	$80.97	7.94	30.4	$80.97
2015	26.1	61.3	$70.09	6.87	28.4	$72.94
2016	26.2	61.3	$81.71	9.34	27.7	$83.78
2016	28.0	62.0	$80.97	7.94	30.4	$80.97

[1] Price (U.S. dollars per metric ton), [2] Million metric tons.

Source: Stephen M. Jasinski, USGS Mineral Industry Surveys.

Figure 1

U.S. portion of world phosphate production (modified from data compiled by D.A. Buckinghame and S.M. Jasinski, USGS.)

things, plants and animals alike. There currently is no economical alternative to phosphate rock as the major source of phosphorus.

Prices

The average value of phosphate rock produced at the mines in crop year 2016 increased over the 2015 crop year prices. The 2016 crop year average price of \$81.71/t (\$74.12/st) is 16.6 percent more than the average crop year 2015 price of \$70.09/t (\$63.59/st) (Table 3).

The 2015 average price of phosphate at the mine was \$78.59. The 2016 average price at the mine was reported at \$100.79/t (\$91.45/st), which is less than the 2015 average price of \$115.16/t (\$104.47/st).

Morocco: The Morocco phosphate rock prices (at 70 percent BPL) peaked in October and November of 2015 at \$123/t (\$111.58/st). In December of 2015, prices began to decline, leveling off again at \$115/t (\$104.33/st) in February through July of 2016. Prices continued to decline in 2016 and fell to \$99/t (\$89.81/st) in January of 2017.

Fertilizers. DAP and TSP spot prices, Tunisia granular f.o.b., bottomed in December 2016 and have been steadily increasing in the first quarter of 2017. Since the change in phosphate rock prices generally parallels the changes in DAP and TSP prices some increase in phosphate rock prices may be expected in 2017.

Industry news

There are currently only two phosphate rock producers mining in Florida, one in the Central District (Mosaic) and one in the North District (Potash Corp. of Saskatchewan [PCS]). In September of 2016, one of the Florida producers, PCS, and a western phosphate producer, Agrium, announced the potential merger of these two Canadian-based fertilizer companies. Shareholders of the two companies have overwhelming approved the merger. The merger is expected to be completed in the spring of 2017.

There are currently three producers, Monsanto (P-4), Agrium and Simplot, operating in the western states of Utah and Idaho. All producers are developing/permitting replacement mines for mines nearing exhaustion of reserves. The new mines will generally be located near existing facilities. In addition, in an another location in Eastern Idaho, on private land, Stonegate-Agricom is continuing to investigate opening an underground phosphate mine on the Paris-Hills property.

In December 2016, Mosaic entered into an agreement to acquire Vale S.A.'s global phosphate and potash operations. The acquisition will include five Brazilian phosphate rock mines, chemical plants and potash mines and will increase Mosaic's interest in the Miski Mayo Mine (Bayovar Mine in Northern Peru) to 75 percent.

The Saudi Arabian producer, Ma'aden Wa'ad Al Shamal Phosphate Co., is approaching completion of its phosphate

Table 2

Phosphate production, U.S. position.

World production [1]						
	Tons [1,2]					
Calendar Year	World	China	Morocco[3]	U.S.	U.S., Percent	Morocco[3] Percent
2006	142.0	30.7	27.0	30.1	21.20	19.01
2007	156.0	45.4	27.0	29.7	19.04	17.31
2008	161.0	50.7	25.0	30.2	18.76	15.53
2009	166.0	60.2	23.0	26.4	15.90	13.86
2010	181.0	68.0	25.8	25.8	14.25	14.25
2011	198.0	81.0	28.0	28.1	14.19	14.14
2012	217.0	95.3	28.0	30.1	13.87	12.90
2013	225.0	108.0	26.4	31.2	13.87	11.73
2014	218.0	100.0	30.0	25.3	11.61	13.76
2015	241.0	120.0	29.0	27.4	11.37	12.03
2016	261.0	138.0	30.0	27.3	10.46	11.49

[1]Estimate for 2015, [2]Million metric tons, [3]Includes Western Sahara.

Source: Stephen M. Jasinski, USGS Mineral Commodity Summaries, January 2015, pp 118-119.

Table 3

Phosphate rock prices[1].

Phosphate use	Crop year				
	2011	2012	2013	2014	2015
Domestic production (f.o.b. mine)	$98.36	$99.58	$80.60	$70.09	$81.71
Percent change from prior year	4.95%	1.24%	-19.06%	-13.04%	16.58%
Exports (f.o.b. port)	N/A	N/A	N/A	N/A	N/A
Imports (CFI)	$151.05	$145.70	$111.24	$109.71	$112.13

[1] Price (U.S. dollars per metric ton). Source: USGS Mineral Industry Surveys.

project and is expected to have the first tonnage produced in late 2017.

In spite of the low prices in past few years, the world capacity to produce phosphate rock is expected to continue to increase as a result of many other phosphate mine expansion projects. Although slowed by recent low prices, active exploration and feasibility studies of the potential for development of phosphate deposits worldwide are ongoing.

The majority of the growth in phosphate production since 2000 has principally been in China (Fig. 1 and Table 2). China has transitioned from the largest importer of phosphate to the largest exporter of phosphate. At the present time, China is reported to be ahead of the U.S. in exports of all phosphate products, except MAP. In addition, China is the largest exporter of P_2O_5 products in the world. However, in early 2017 it is reported that exports from China have tightened.

Environmental, regulator and reclamation issues

Mosaic has been in the process of permitting four new mining areas in central Florida. Two of the applications are extensions of existing mines and two are for new mines. In November 2016 the Army Corps of Engineers (Corps) issued a federal wetlands permit for the extension of an existing mine. However, local and national environmental groups are threatening to seek legal action to prevent issuance of permits. Because of the difficulties of permitting in Florida, there are numerous permitting activities ongoing in the western states.

Exploration activities on Western phosphate lands have been extensive over the past few years. The permitting activities include extensions of existing phosphate mines, expansions of existing mines, or new phosphate mines. According to the Pocatello, ID field office of the U.S. Bureau of Land Management, there are five EISs in process at the present time assessing mining proposals on federal phosphate leases and National Forest System lands. The Pocatello Field Office continues to evaluate five mine plan applications. The processing of one environmental impact statement (EIS), Agrium's Husky-North-Dry Ridge Mine, has been temporarily idled/put on hold at the applicant's request. The Agrium Rasmussen Valley EIS was completed in January 2017. Three other final EIS decisions are expected in the Fall of 2018 including the Simplot East Smoky Mine extension, the Simplot Dairy Syncline Mine, and the P-4 (Monsanto) Caldwell Canyon Mine. In addition, in an another location in Eastern Idaho, on private land, the Idaho Department of Environmental Quality was working with another company, Stonegate-Agricom, on the Paris-Hills underground property. However, the new underground mine is not expected to begin production until after 2018.

It has been reported that environmental pressures in China may have led to a reduction in Chinese phosphate exports.

Trends and outlook

The worldwide demand for phosphate fertilizers is expected to increase gradually in proportion to the increase in the world population. The leading plans for growth are reported to be in Africa and the Middle East. The USGS predicts worldwide phosphate production will incrementally increase to double capacity by 2020.

Continued depletion of high-yield deposits of ore in Florida and the environmental restrictions being placed on U.S. facilities will result in stable or declining production capacity from some of the existing and proposed U.S. facilities, which will limit the U.S. production. U.S. production is expected to gradually decline as a percentage of total world production as U.S. reserves are depleted and as other countries continue to increase production as a result of the increased global competition in the fertilizer industry. As a result, domestic phosphoric acid production is also expected to slowly decline as a percentage of world production capacity.

Most of the near-term increase in world production is expected to occur in Morocco and Saudi Arabia, while expansion in China is reported to have slowed. The leading plans for growth in the near future are in Africa and the Middle East. Morocco has predicted it will double mine production with the goal of producing 40 percent of the world's supply of phosphate by 2020 through the expansion of existing mines and phosphate processing plants such as the large Office Che´rifien des Phosphates four new phosphate centers. The Ma'aden II start-up in Saudi Arabia which is a new 5.3 Mt/a (5.8 million stpy) phosphate mining and processing facility is planned for late 2017.

By 2020, other potentially significant projects are expected to come on line in Algeria, Brazil, Egypt Jordan, Kazakhstan, Peru, Russia and Senegal.■

POTASH

by S.M. Jasinski, National Minerals Information Center, U.S. Geological Survey

In 2016, during January through June, potash production dropped to its lowest levels in more than four years, because potash demand decreased from that of 2015. Stocks increased and prices decreased as a result. Major producers curtailed production in response to the weak demand and high potash inventories. In the second half of the year, production increased to meet increasing demand and consumption increased mainly owing to lower potash prices and a recovery in crop prices. World production was estimated to be 39 Mt (43 million st) of potassium oxide (K_2O), which was slightly less than that of 2015. United States estimated production in 2016 decreased to 520 kt (573,000 st) of K_2O from 740 kt (815,000 st) of K_2O in 2015, owing mainly to Intrepid Potash Inc. ceasing production of muriate of potash (MOP) from its underground mines in New Mexico. Intrepid continued to mine higher-value potassium-magnesium sulfate (SOPM) from one underground mine in New Mexico and produce MOP from lower-cost solar evaporation and solution mines in New Mexico and Utah.

Estimated consumption of potash by the United States was 9 percent lower than that of 2015, because of lower agricultural use and a drop in industrial potash uses, primarily for oil well-drilling additives during the first half of the year. According to a December 2016 report from the International Fertilizer Association, world consumption of all forms of potash in 2016 was 39.6 Mt (43.6 million st) of K_2O, compared with 39.5 Mt (43.5 million st) in 2015. Canada continued to lead the world in potash production. Russia, Belarus, China and Germany were other leading producers, in descending order of output. The United States ranked eleventh in world production.

The majority of domestic potash was produced near Carlsbad, NM, with most of the potash coming from the mineral sylvite. Potash encompasses a variety of mined and manufactured salts, all of which contain the element potassium in water-soluble form. The term potash, however, also can refer specifically to potassic fertilizers, which are potassium chloride [(KCl) or the mineral sylvite], potassium sulfate [(K_2SO_4) or sulfate of potash (SOP), usually a manufactured product], and SOPM [($K_2SO_4 \cdot 2MgSO_4$) or langbeinite or double sulfate of potash magnesia]. MOP for fertilizer use is an agriculturally acceptable mix of KCl (95 percent pure or greater) and sodium chloride (halite) that includes minor amounts of other nontoxic minerals from the mined ore and is neither the crude ore sylvinite nor pure sylvite. Because the potassium content of its common salts varies, the potash industry has established a common standard of measurement for defining a product's potassium content (or purity) related to the approximate K_2O content.

Because it is a source of soluble potassium, about 90 percent of potash consumed globally is used as fertilizer (plant nutrient). Potassium is one of the three primary nutrients required for plant growth and maturation; the others are fixed nitrogen and soluble phosphorus. The remaining 10 percent of potash consumed is used to produce potassium chemicals, which are used in applications such as aluminum recycling, animal feed supplements, oil-well drilling mud, snow and ice melting, soap manufacturing, steel heat-treating and water softening.

Globally, most potash is extracted by conventional underground mining methods. Solution mining is used when underground deposits are irregular and (or) very deep. Potash also is produced by the evaporation of brines in shallow salt lakes, followed by the harvesting of potassium minerals.

Industry developments

North America is the leading potash-producing region in the world, with 38 percent of global capacity, the majority of which is in Canada. Three companies in Canada produced potash: Agrium Inc.; Potash Corp. of Saskatchewan Inc. (PotashCorp) and The Mosaic Co. In 2016, Agrium and PotashCorp announced a merger agreement. The companies expected to complete the merger in 2017, pending regulatory approval in Canada and the United States. The combined company would have 24 percent of world MOP capacity. In 2016, PotashCorp completed a 3-Mt/a (3.3 million stpy) increase of MOP capacity at its Rocanville, Saskatchewan mine. This offset the indefinite closure of its 2 Mt/a (2.2 million stpy) of MOP Picadilly Mine in New Brunswick, which was idled in January because of a global oversupply of potash.

In Saskatchewan, several larger potash properties were in various stages of development in 2016. K+S Aktiengesellschaft commissioned its 2.86-Mt/a (3.15 million stpy) solution mine in 2016 and planned to ramp up production in 2017 to close to the initial 2 Mt/a (2.2 million stpy) of MOP capacity. K+S planned to add 860 kt/a (947,000 stpy) of MOP capacity after 2020. BHP Billiton holds exploration rights to about 14,500 km^2 (5,600 sq miles), which includes five potash properties and continued with development activities at the Jansen project east of Saskatoon. The Jansen Mine was designed to produce up to 8 Mt/a (8.8 million stpy) of MOP, but BHP was not expected to begin production until well after 2020, depending on market conditions.

IC Potash Corp. (Canada) continued with construction of a new underground potash mine in

Lea County, NM, east of Carlsbad. The mine was designed to produce 650 kt/a (716,000 stpy) of SOP only. Initial production was expected to begin after 2018.

Compass Minerals International Inc. expected to complete a 210-kt/a (230,000-stpy) expansion of SOP production capacity at its solar evaporation facility on the Great Salt Lake in Utah in 2017, increasing its SOP capacity to 500 kt/a (550,000 stpy).

In Russia, Uralkali continued work on modernization of its processing facilities and construction of new mines at Solikamsk, Polovodovsky and Ust-Yayvinsky that would increase its capacity incrementally to 18.7 Mt/a (20.6 million stpy) of MOP after 2020 from 12.4 Mt/a (13.6 million st) of MOP in 2016. Uralkali accelerated the schedule for expansion after its Solikamsk 2 mine was flooded in late 2014, reducing Uralkali's production capacity by 2 Mt/a (2.2 million stpy). The company plans to complete a new underground mine at Solikamsk 2 by 2020 to mine the remaining reserves.

EuroChem MCC, OJSC had two mines in development. The VolgaKaliy project, which would mine potash ore from the Gremyachinskoe deposit, was scheduled to be completed in two phases, each with a production capacity of 2.3 Mt/a (2.5 million stpy) of MOP. The first phase is projected to open in 2018, and the second phase is expected to be completed after 2020. The Usolskiy project, which would exploit the Verkhnekamskoe deposit, also is planned to be completed in two phases. The first phase of production was expected to commence in 2018, with a capacity of 2.3 Mt/a (2.6 million stpy) of MOP. The unscheduled second phase would add 1.4 Mt/a (1.5 million stpy) of MOP to the production capacity.

In Turkmenistan, the Garlyk Mine was expected to begin production is mid-2017. The underground mine, which will be operated by Turkmenkhiya State Concern, will have an initial capacity of 1.4 Mt/a (1.5 million stpy)of MOP.

Other significant potash projects were under development in Australia, Brazil, Canada, Congo (Brazzaville), Eritrea, Ethiopia, Kazakhstan, Laos, Peru, Thailand and the United Kingdom. None of these projects, however, is expected to be completed before 2020.

Outlook

Potash is an essential fertilizer nutrient for which there is no substitute. Growing world population and its need for food will require continued growth in potash production and consumption. Additionally, increased ethanol production from corn and other crops will require a proportional growth in fertilizer use.

Global potash production capacity was expected to increase to 57.6 Mt/a (63.5 million stpy) of K_2O in 2017 from 54.9 Mt/a (60.5 million stpy) of K_2O in 2016 from projects in Canada, China, Russia and Turkmenistan.

Potash consumption, for all uses, is projected to increase to 40.6 Mt (44.7 million st) of K_2O in 2017 from 39.6 Mt (43.8 million st) in 2016, based on projected world increases in fertilizer and industrial uses, mainly in Asia and South America. In 2017, world potash production is forecast to increase slightly from 39 Mt (43 million st) of K_2O in 2016. ■

PUMICE AND PUMICITE

by R.D. Crangle, Jr., National Minerals Information Center, U.S. Geological Survey

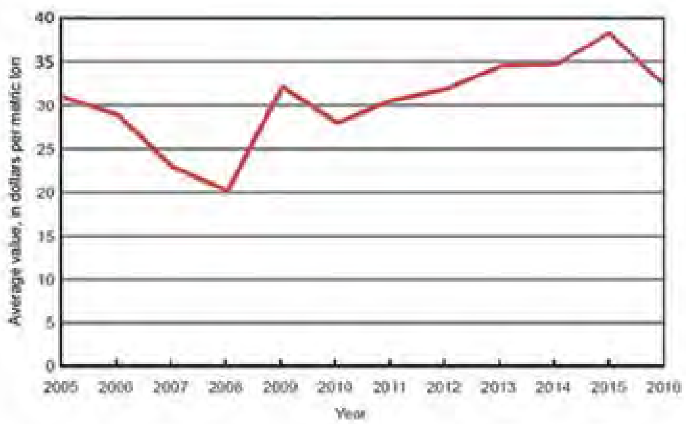
Mine production of pumice in the United States during 2016 was estimated to be 310 kt (342,000 st), about the same as that of 2015. The unit value of pumice varied widely by end use in 2016. Pumice used in the fabrication of building block was priced at \$18.50/t (\$16.80/st) but specialty-grade pumice, used in cosmetics, filtration or precision grinding, could be priced as high as \$11,000/t (\$10,000/st), or more, on a spot basis. Since 2005, the average unit value of pumice has ranged from \$20/t to \$39/t (\$18/st to \$35/st) (Fig. 1). Ten companies operated mines in California, Idaho, Kansas, New Mexico and Oregon. U.S. pumice exports totaled about 8.6 kt (9,500 st). Imports were higher at 170 kt (187,000 st).

World resources of pumice are adequate for the foreseeable future. However, transportation costs may encourage development of deposits closer to markets. Total world production of pumice was estimated to be 16.9 Mt (18.6 million st) in 2016. The United States was estimated to rank 11th globally in pumice production in 2016. Pumice is used more extensively as a building material outside the United States, which explains the large global production of pumice relative to that of the United States. The top world producers in 2016 were, in descending order of production, Turkey (6.7 Mt or 7.4 million st), Italy (4 Mt or 4.4 million st) and Chile (830 kt or 915,000 st).

Pumice is an extrusive igneous volcanic rock formed through the cooling of air-pocketed lava, which results in a highly porous, low-density rock. The low density allows some pumice to float on water. Large pumice rafts, consisting in some instances of thousands of individual pieces of pumice clumped together, are a unique geologic phenomenon and have been documented to be as long as 30 km (19 miles) and to have drifted for several years in oceanic waters. Pumicite is defined as grains, flakes, threads and (or) shards of volcanic

Figure 1

Average unit value of pumice (freight on board mine or mill) expressed in U.S. dollars per metric ton, 2005 to 2016, not including outlier specialty-grade pumice (USGS).



glass finer than 4 mm (0.20 in.) in diameter. Pumicite and volcanic ash are descriptive terms that are often used interchangeably. The porous, lightweight properties of pumice are well suited for its main use as an aggregate in lightweight building blocks and assorted building products.

Processing and uses

Pumice is usually extracted by simple openpit methods using rippers, bulldozers and front-end loaders. Processing typically is limited to drying, crushing, and screening, although some abrasive grades may require fine grinding and classification. Although the generation and disposal of reject fines in mining and milling resulted in local dust issues at some operations, the environmental impact was restricted to a relatively small geographic area. Pumice blocks may be sawn into a variety of shapes and sizes. In 2016, other major applications included abrasives and horticulture (including landscaping). Minor applications include the use of pumice as an absorbent, as a concrete aggregate and admixture, as a filter aid, and as a traction enhancer for tires. A small percentage of pumice was used in abrasive-type products, including pencil erasers, polishing agents for circuit boards and television monitors, tooth-filing mechanisms for chinchillas, exfoliants in cosmetics and a variety of heavy-duty hand cleaners. Imports were primarily used as raw material for building block (e.g., cinderblock) and other lightweight aggregate applications. Several substitutes exist for pumice in agriculture, in horticulture, as an aggregate, as a concrete additive and in other end products.

Outlook

Although pumice and pumicite are plentiful in the western United States, legal challenges and public land designations could limit access to known deposits. Pumice and pumicite production is sensitive to mining and transportation costs. An increase in fuel prices would likely lead to increases in production expenditures; imports and competing materials could become attractive substitutes for domestic products. ■

RARE EARTHS

by J. Gambogi, National Minerals Information Center, U.S. Geological Survey

Global mine production of rare-earth elements (REE) in 2016 was estimated to have been 126 kt (138,000 st) of contained rare-earth oxide (REO) equivalent and was primarily from the rare-earth ore minerals bastnäsite, loparite, monazite, xenotime and lateritic ion-adsorption clays (Table 1). China dominated the global mine production as well as the production of rare-earth metals and compounds. In 2016, China set its REO mine production quota at 105 kt (116,000 st) of REO equivalent; however, this amount was supplemented by an undocumented quantity of REOs that have been produced in China and elsewhere.

REO mine production outside of China included production from new capacity in Australia and byproduct production from heavy minerals, phosphate, uranium and other mining operations and from mine tailings in Brazil, India, Malaysia, Russia, Thailand, Vietnam and other countries.

In Australia, Lynas Corp. continued to operate its Mt. Weld mining operations on a campaign basis in line with the scale up of its operations in Malaysia. In 2016, Lynas' Malaysian operations produced 13.9 kt (15,300 st) of REO equivalent derived from imports of Australian rare-earth concentrates, a 27 percent increase compared with production in 2015.

Brazil was estimated to have produced 1.1 kt (1,300 st) of REO equivalent in mineral concentrates in 2016. REO concentrates were produced from a stockpile of previously mined heavy mineral concentrates. In recent years, monazite concentrates were shipped from Brazil to processors in China. In 2016, the gross weight of these shipments was reported by China Customs to be 3.7 kt (4,100 st). Companhia Brasileira de Metalurgia e Mineração was reported to be piloting the production and separation of REOs derived as byproduct of its niobium mining operations in Araxá.

In China, the government set the REO mine production quota at 105 kt (116,000 st) in 2016, unchanged from that of 2015. As part of its efforts to consolidate the industry, China's Ministry of Land and Resources (MLR) allotted the majority of the mining quota to six business entities. China continued to be the world's leading exporter of rare-earth metals

Table 1

Global: Estimated rare earth mine production (data in metric tons of rare-earth oxide (REO) equivalent[1].

Country	2011	2012	2013	2014	2015	2016[e]
Australia	2,190	3,220	3,000	8,000	12,000	14,000
Brazil	140	110	330	–	880	1,100
China[2]	93,800	93,800	93,800	105,000	105,000	105,000
India	1,700	1,700	1,700	1,700	1,700	1,700
Malaysia	410	100	180	240	500	300
Russia	2,500	2,400	2,500	2,600	2,800	3,000
Thailand	3,100	120	130	1,900	760	800
United States	–	3,000	5,500	5,400	5,900	–
Vietnam	200	200	100	–	250	300
Total (rounded)	104,000	105,000	107,000	125,000	130,000	126,000

Source: U.S. Geological Survey
[e] Estimated prior to yearend
[1] In addition to the countries listed, rare-earth minerals are thought to be produced in other countries, but information is inadequate for formulation of reliable estimates of output levels.
[2] Production quota. Illegal production could not be quantified.

and compounds. In 2016, according to gross weight data compiled from IHS Inc., China exported 42 kt (46,000 st) of rare-earth compounds and 5.2 kt (5,700 st)of rare-earth metals (excluding ferrocerium), compared with 29.2 kt (32,200 st) of compounds and 5.6 kt (6,200 st) of metals and in 2015. In 2016, Japan (34 percent) and the United States (25 percent) were the leading destinations of China's exports of rare-earth compounds. Japan (67 percent) was the leading destination for China's exports of rare-earth metal. China's imports of rare-earth compounds and metals (excluding ferrocerium) were 16.5 kt and 15 t (18,000 and 16.5 t), respectively. The leading sources of China's imports were, in descending order, Malaysia, Myanmar and Russia.

India has significant production of heavy-mineral sands normally associated with monazite production. In 2016, India's government-owned Indian Rare Earths Ltd. (IREL) was ramping up capacity at a recently commissioned plant in Odisha that was expected to produce as much as 11 kt/a (12,100 stpy) of mixed rare-earth chlorides (MREC) from monazite concentrates. In 2016, India imported about 550 t (606 st)of rare-earth compounds and 450 t (496 st) of rare-earth metals. India's exports of rare-earth compounds were 440 t (485 st).

Russia's Lovozersky GOK produced loparite concentrates from its Karnasurt Mine in Murmansk. Loparite concentrates were further processed into MREC by Solomansk Magnesium Works (SMW). Russia's mine production of REOs was estimated to have been 3 kt (3,300 st) in 2016. Russia's exports of REE compounds totaled 6.6 kt (gross weight) in 2016, a 6 percent increase compared with exports in 2015. Estonia (90 percent) was the leading destination for exports from Russia.

Several countries produced and exported byproduct monazite and xenotime from the processing of heavy-mineral sands. In gross weight, Thailand (2.7 kt or 2,900 st), Vietnam (400 t or 440 st), and Mayalysia (300 t or 330 st) all exported mineral concentrates to China.

In the United States, there was no production of rare-earth mineral concentrates. Molycorp. Inc. idled its mining operations at Mountain Pass in 2015, and the operation remained idle in 2016, leaving the United States 100 percent import reliant. U.S. production of rare-earth alloys, compounds and chemical intermediates were produced from imports and inventoried materials. Eutectix, LLC acquired Molycorp's metals and alloys operations at Tolleson, AZ. In Nebraska, Rare Earth Salts planned to produce separated rare-earth compounds from phosphor powder recovered from spent compact fluorescent light bulbs.

Consumption

According to estimates published by Roskill Information Services, Ltd., global consumption of

Figure 1

Lanthanum, cerium, neodymium and yttrium rare-earth oxide prices U.S. dollars per kilogram (f.o.b. China)

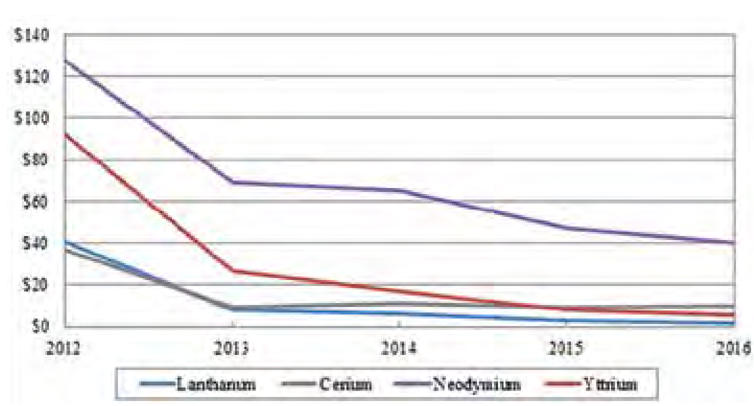
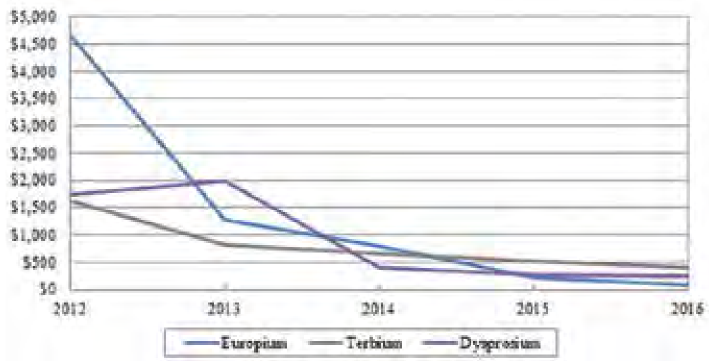


Figure 2

Europium, terbium and dysprosium rare-earth oxide prices U.S. dollars per kilogram (f.o.b. China).



REOs was about 123 kt (135,000 st) in 2016. The leading end uses for rare earths represented about 75 percent of global consumption and included, in descending order, catalysts, magnets, polishing, batteries and metallurgy. The remaining 25 percent included glass, ceramics, phosphors and other uses. China, other countries in Asia and the United States represented about 70 percent, 15 percent, and 15 percent, respectively, of global consumption.

Japan's Society of Newer Metals estimated the 2016 consumption of rare earths in Japan at 16.8 kt (18,500 st), a 9 percent increase compared with 15.4 kt (17,000 st) in 2015. The breakdown of consumption included cerium (5.8 kt or 6,400 st), europium (13 t or 14 st), lanthanum (1,980 t or 2,100 st), mixed rare-earth metals (3.5 kt or 3,800 st), praseodymium-neodymium (4 kt or 4,400 st), samarium (80 t or 88 st), yttrium (820 t or 904 st) and other rare earths (613 t or 675 st).

In the United States, consumption of rare earths in metals and compounds was estimated to have been 16 kt (17,600 st) of REO, and the estimated distribution of rare earths by end use, in decreasing order, was as follows: catalysts, 55 percent; metallurgical applications and alloys, 15 percent; glass polishing and ceramics, 10 percent; polishing, 10 percent and other, 10 percent.

Prices

Despite the consolidation of industry and efforts to curtail production capacity, excess mine and separation capacity in China continued, and prices for most rare-earth products declined in 2016 (Figs. 1 and 2). In general, prices declined less severely than in prior years. Based on export data from China Customs, prices for lanthanum, neodymium and yttrium decreased by 30 percent, 15 percent and 35 percent, respectively, compared with prices in 2015. Prices for the heavy rare earths, europium and terbium, decreased by 57 percent and 23 percent, respectively. Demand for magnets limited price decreases for dysprosium oxides to 4 percent compared with 2015. Contrary to most rare-earth price trends, prices for cerium oxide (used in polishing compounds and autocatalysts) increased by 6 percent compared with those in 2015.

Reserves

Global reserves of REOs in 2016 were estimated to be 120 Mt (132 million st). Reserves of REOs in the United States included an estimated 1.4 Mt (1.5 million st) that were compliant with the international industry standards. Exploration and development efforts were slowed by falling prices of most rare-earth materials; however, projected growth in demand supported continuing exploration and development projects worldwide.

Outlook

Global consumption of rare earths is expected to increase at a compound annual growth rate in excess of 5 percent from 2015 through 2020. Rare-earth use, particularly in catalysts, magnets, hydrogen storage alloys and polishing compounds is expected to continue to rise as future global demand for alternative energy sources, automobiles, consumer electronics and industrial motors increases. Demand for cerium and lanthanum for use in automotive catalytic converters and catalysts for petroleum refining is expected to trend with the production of automotive production and the refining of heavy crude oil; however, rare-earth use in fluid catalytic cracking will be influenced by the cost competitiveness of reformulated catalysts with lower REO content. Similarly, demand for neodymium, praseodymium and dysprosium are expected to trend with demand for neodymium-iron-boron permanent magnets. Progress on the commercialization of new uses for cerium and lanthanum may help alleviate shortages of certain heavy rare-earth elements. ■

SALT

by H. John Head, Q4 Impact Group

Salt remains the most cost-effective material for maintaining full mobility on roads and highways and to prevent accidents during the winter snow season. It is also the most useful component for regenerating the ion exchange resins used for water conditioning. It is critical in the production of animal feed products and the most ubiquitous ingredient used in the food industry.

Since 2005, China has been the world's largest salt producer, with 2016 production estimated to be 58 Mt (63.9 million st) by the U.S. Geological Survey, while the total U.S. salt production (including brine directly captured for the chemical industry) was estimated at 42 Mt (46.3 million st). Combined, both countries accounted for about 39 percent of total world production, while the six other countries producing more than 10 Mt (11 million st), produce a total of 75 Mt (82.7 million st) or 29 percent. The production and sales of salt in the United States differs significantly from year to year as a result of fluctuations in the weather, since the primary market for non-brine salt is for highway deicing. Other salt markets are steady and consistent. Most of the production in the salt industry is dry salt, because U.S. chemical manufacturers commonly control their own captive brine sources.

Total U.S. salt sales amounted to 42 Mt (46.3 million st) in 2016, a decrease of 3 Mt (3.3 million st) over the estimated 2015 volume due to the milder winter weather and reduced highway salt requirements. Water conditioning and food grade salt sales remain stable.

The total value of U.S. salt sales was estimated to be $2 billion. Average prices for rock salt have increased from $35.67/t ($32.36/st) in 2010 to $49.6/t ($45/st) in 2016, however average prices in 2016 dropped some 6 percent from the high in 2014, due to milder weather and reduced demand.

Imports and exports

The U.S. imported an estimated 12.5 Mt (13.8 million st) of salt in 2016, a significant reduction of 9.1 Mt (10 million st) from the figure of 21.6 Mt (23.8 million st) in 2015.

U.S. salt exports dropped to an estimated 650 kt (717,000 tons) in 2016 from 839 kt (925,000 st) in 2016.

Key market forces

Salt is the most commonly used agent for de-icing and anti-icing to combat snow and ice buildup on winter roadways; in the United States, it represents 44 percent of rock salt production. In North America, the biggest factor affecting salt production levels, price and availability is the severity of the winter season. An example of this cycle: heavier winter conditions in 2014-2015 resulted in higher usage for de-icing, the demand for de-icing salt in the winter of 2015-2016 was significantly lower, due to a milder winter caused by the El Nino effect in the western Pacific Ocean; 2016-2017 brought a mixed bag – less severe weather in the mid-west and heavier snows in the northeast. The cycles are frequently made worse by fluctuating inventory levels and the timing of the cold weather. Mild winters, like that in 2015-2016, leave high inventories in place and unless the cold weather arrives early in the winter season, municipalities resist restocking them until the following year.

Issues, events and trends

A new study published in the Proceedings of the Natural Academy of the Sciences (Salting our freshwater lakes) purports to sound the alarm about rising chloride levels in North American lakes. Yet, as noted by the Salt Institute, the study actually found that chloride levels in the majority of the examined lakes either stayed the same or declined and that chloride levels were far below U.S. Environmental Protection Agency (EPA) toxicity standards. Chloride concentrations across all 371 lakes in the study had a median of 6 mg/L, while the EPA standard is 230 mg/L. The fact is that several studies have shown that when road salt is properly applied environmental impacts can be effectively managed and significantly minimized. Modern roadways themselves are not a natural feature of the environment and are specifically engineered to satisfy our demand for personal and commercial mobility – factors that are basic to the quality of life. This includes sensible salting when needed to protect lives and commerce.

Many Chicago municipalities use salt brine as one tool for de-icing. This can be seen as parallel wet lines on the road, generally before the snowy or icy conditions start. The Salt Institute reports that the use of salt brine allows for states and localities to keep roads clear while using less salt, resulting in significant financial savings as well as protecting the environment. Since the late 1990s brine anti-icing strategy has become one of the most popular winter road maintenance strategies across North America. ■

Table 1

Global salt production.

Country	Production (Mt)	
	2014	2015 (est)
United States[1]	45.0	42.0
Australia[2]	11.0	12.0
Brazil	7.5	7.5
Canada[2]	12.5	10.0
Chile[2]	11.8	11.0
China[1]	70.0	58.0
France	6.0	6.0
Germany[2]	12.5	12.5
India[2]	17.0	19.0
Mexico[2]	10.5	10.5
Poland	4.2	4.2
Spain	4.3	4.3
Turkey	6.0	6.0
Ukraine	6.1	6.1
United Kingdom	5.0	5.0
Other countries	42.0	41.0
World Total	**271.4**	**255.1**

[1] U.S. and China (100 Mt total)
[2] Five second tier producers (75 Mt total)

SODA ASH

by Jonathan Kuhn, Tronox Alkali

Sodium carbonate, otherwise known as soda ash, is a basic alkali used in an array of industrial processes. Roughly half of the world's production is consumed in the manufacturing of glass in various forms – architectural glazing, windshields, tableware, etc. The other half of the world's production is consumed in a variety of industrial segments including the production of other inorganic chemicals, detergents and water and air treatment applications.

Soda ash is largely produced by either refining a naturally occurring ore (such as trona or nahcolite) or by reacting carbon dioxide with an ammoniated brine to form the alkali compound in what is referred to as a synthetic process. Naturally produced soda ash benefits from lower production costs, lower energy consumption and minimal environmental impact compared to synthetic production methods. Roughly a quarter of the world's supply is produced from natural sources with three quarters of this capacity concentrated in the United States due to the plentiful ore deposits in Southwestern Wyoming. Due to the lack of ore reserves in other regions of the world, roughly three quarters of the global capacity was developed based on the synthetic process with the majority using a process developed by Ernest Solvay which produces soda ash along with a calcium chloride byproduct. This process was modified by Debang Hou to a process that produces soda ash and ammonium chloride as the byproduct to be marketed as a fertilizer.

Global demand and supply

Global soda ash demand in 2016 is estimated at more than 56 Mt (62 million st), up about 1 percent from 2015. U.S. demand for soda ash in 2016 was 5.1 Mt (5.6 million st). Demand in the United States grew about 3 percent, while demand growth in China was about 1 percent. While China remains the largest consumer and producer of soda ash in the world, both demand and capacity growth have slowed since 2013 and other regions of the world including Southeast Asia, Indian Subcontinent and Middle East have grown at a more rapid pace in the same period. United States production of soda ash in 2016 increased 2 percent to 11.8 Mt (13 million st). The increased production was supported by strong demand for U.S. natural soda ash in export markets. The U.S. soda ash industry exported 6.8 Mt (7.5 million st) in 2016, an increase of 6 percent from 2015. The increased demand for natural soda ash is driven by the cost competitiveness of U.S. production in export regions well as the favorable sustainability profile due to lower environmental impact of natural soda ash versus synthetic derived soda ash.

Pricing

Global prices of soda ash have generally been rebounding since the global recession as excess effective capacity has largely been rationalized and global demand continues to grow at 1-2 percent per year. From 2013 to 2016, roughly 2 Mt (2.2 million st) of capacity outside China was retired. During 2016, Chinese government focused on eliminating overcapacity in a number of industrial markets and utilized increased environmental checks in an effort to reduce industrial pollution. While the majority of global soda ash capacity is based on the Solvay process, the majority of the capacity in China is based on the Hou process. Due to a chronic oversupply in the fertilizer market, the value of ammonium chloride has fallen significantly since 2013, resulting in higher costs for Hou based production and a higher floor for Chinese market pricing. Natural soda ash production remains fully utilized with producers following regional market trends to stay competitive with the local synthetic production or other imports. Domestically, U.S. prices show much less volatility compared to most global regions due to a mature market demand and longer term supply relationships.

Outlook

U.S. demand for soda ash is expected to grow about 2 percent in 2017 compared to 2016, primarily due to increased demand from the flat glass and chemicals segments as a result of increased construction activity. Demand for soda ash in developing economies is expected to continue to grow at a faster rate than markets in the United States, Western Europe and China. Overall, global soda ash demand is expected to grow about 2 percent annually over the next five-year period. Natural soda ash production is expected to increase between 2017 and 2019 as deposits in Turkey are developed. This new production as well as production in the United States is well positioned to participate in the global demand growth as their low cost position allows them to maintain full plant utilization and profitability. ■

STRONTIUM

by S.A. Singerling, National Minerals Information Center, U.S. Geological Survey

In 2016, U.S. apparent consumption of strontium (contained in celestite and manufactured strontium compounds) was 10.8 kt (11,900 st), 66 percent less than that in 2015. The gross weight of total imports of strontium compounds and minerals in 2016 of 21.6 kt (23,800 st), 76 percent of which originated in Mexico, was 69 percent less than that of 2015. In 2016, the average U.S. Customs value of imported strontium carbonate was \$0.81/kg (\$0.37/lb), and for strontium nitrate, the average value was \$1.24/kg (\$0.56/lb). Imports of celestite decreased by 82 percent from those of 2014, the first decrease since 2010. The average value of imported celestite increased by 53 percent to \$78/t (\$71/st).

Figure 1 illustrates the variation in some salient strontium statistics from 1986 through 2016. U.S. consumption of strontium chemicals (principally strontium carbonate) trended upward during the period from 1986 through 2000, followed by a steep decline owing to reduced production of strontium carbonate in the United States and a declining demand for strontium carbonate for color television faceplate glass. Imports of celestite during the first half of the time period depicted were principally for the production of strontium chemicals with the gap between domestic production and consumption filled by increasing volumes of imports. The recent increase in celestite imports likely was a result of increased drilling for oil and gas and increased use of celestite as an additive to drilling fluids. However, the dramatic decrease in the number of active oil and gas drilling rigs during 2015 caused a sharp decrease in celestite imports in 2016.

Although strontium is the 15th most abundant element in the Earth's crust, only the minerals celestite (strontium sulfate) and strontianite (strontium carbonate) contain strontium in sufficient quantities to make recovery practical. Celestite has been the leading source of strontium since the 1870s because it occurs more frequently in economically attractive sedimentary deposits. The largest celestite deposits are found in China, Iran, Mexico, Spain and Turkey, although no production is currently reported for Iran and Turkey, most likely the result of declining demand. Deposits of strontianite have been identified in China and Malawi, but production has been reported only from China.

The world's leading producers of celestite are China, Mexico, and Spain. Of an estimated 350 kt (390,000 st) of celestite produced worldwide in 2016, 99 percent was produced in those countries. Although celestite deposits occur in the United States, no celestite has been mined domestically since 1959.

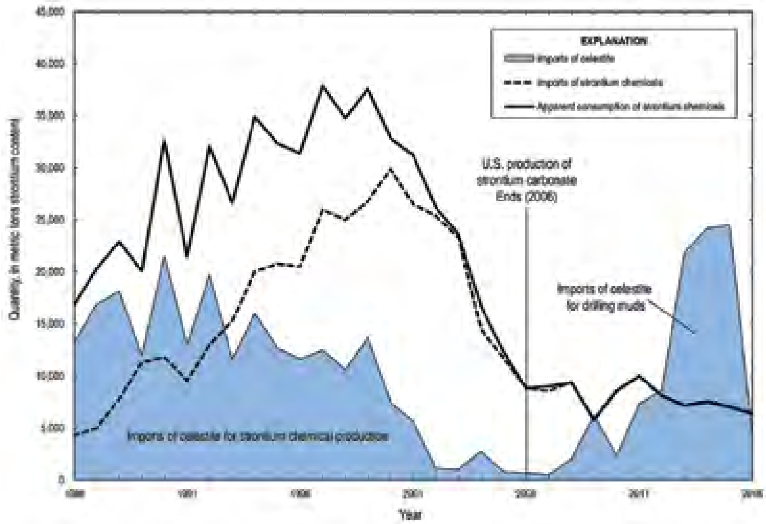
Celestite is rarely consumed directly, except as an additive to drilling fluids for oil and natural gas exploration and production, for which celestite is ground but undergoes no chemical processing. In other uses, it is typically converted to strontium carbonate through chemical processing. Strontium carbonate is used directly in some applications and is also converted into downstream chemicals such as strontium chloride, strontium hydroxide, or strontium nitrate.

China is the world's leading producer of strontium carbonate, followed by Germany and Mexico. China uses domestic and imported celestite to supply its strontium carbonate plants; Germany is 100 percent reliant on imported celestite; and Mexico consumes domestic ore for its strontium carbonate production. Celestite reserves in China are smaller and of lower quality than those in the other major producing countries of Mexico and Spain.

Although ceramics and glass manufacture remained among the top end-use industries through strontium's use in permanent ceramic ferrite magnets, in frits in ceramic glazes, and as a glass modifier, strontium carbonate consumption began to collapse in about 2004 when flat panel displays became more affordable, replacing cathode ray tubes (CRTs) in color televisions and monitors; by 2007, all U.S. CRT faceplate glass plants had closed. The use of strontium nitrate in pyrotechnics was estimated to equal the use of strontium carbonate in ferrite magnets in 2016. Other applications include master alloys for aluminum casting, pigments and fillers in corrosion-resistant paints, and electrolytic production of zinc. ■

Figure 1

Some salient statistics for strontium in the United States.



SULFUR

by Jonathan Kuhn, Tronox Alkali

Elemental sulfur is essential to human existence. Without sulfur there would be no human life. Sulfur and its derivatives are key to the formation of protein and amino-acids in plants and animals. In addition to allowing humans to thrive, sulfur is the building block in myriad industrial, feedstuff processing and medicines. Sulfur's pre-eminence commenced as Greeks, Romans and their predecessors recognized it as a special element. Incipient chemistry in the Middle Ages brought further recognition, followed by its crucial role in industrial chemistry from the 19th Century forward. Today, in addition to traditional uses, sulfur and its derivatives are being examined for applications in super-efficient electric storage batteries, as a superconductor and as a component for solar-based electrical generation.

Sulfur's derogatory persona during the Industrial Age is mostly linked to airborne pollution from power generation and industrial processes. The last 50 years' notoriety focused on the dramatic visual impact of acid rain and its resultant environmental degradation. Acid rain's link to deforestation, new-found understanding of respiratory illnesses' ties to sulfur dioxide mist and its being removed from fuels to keep catalytic converters from dying are some of the negative headlines associated with sulfur. While justified, such pollution controls are not exclusive to sulfur. Society is now focused on mitigating the impact of human activities on the entire biosphere, be it eliminating dust generated by farmers at planting, converting sewer plant effluents into potable water, reducing all stack gas emissions, and now sequestering carbon dioxide ... not just sulfur compounds. Unfortunately, many view sulfur as a malignant substance rather than for its essential role in human life: healthy food, medicine, green energy, construction materials, present in innumerable chemical reactions and beneficial products, a natural fungicide and pest repellent, saving life by providing the odor in otherwise odorless natural gas, medicinal salve, etc. Sulfur's role as an essential Fourth Plant Nutrient is increasingly recognized in all types of agriculture – now that aerial deposition no longer provides availability. The Sulphur Institute (TSI) calls sulfur "an advantaged element" for its myriad of uses. TSI represents an excellent resource for furthering readers' knowledge of this element from uses, transportation and safety (sulphurinstitute.org).

Sulfur was historically obtained from volcanic deposits, which limited availability. *Fire and Brimstone: The History of Melting Louisiana's Sulphur* (D. Davis and R. Detro, Louisiana Geological Survey, 1992) may be consulted for further information. Its Latin name translates to "the stone that burns." Thus its historical association with Hades, Satan and the origin of its English appellation - brimstone. An additional online resource for further information regarding this multifaceted element is, *Materials Flow of Sulfur* (J. Ober, USGS 2002, http://pubs.usgs.gov/of/2002/of02-298/).

Sicily, a center of volcanic activity, was the focus of European sulfur availability until the first decade of the 20th Century. Sulfur's essential role in gunpowder manufacture made many Sicilians extremely wealthy. The early 20th Century brought an indisputable paradigm shift to the industry. Herman Frasch developed a process to melt sulfur deposits underground using superheated water, lifting molten sulfur to the surface on a column of compressed air rather than using a pump dependent on mechanical integrity and requiring periodic replacement. Frasch deposits are often associated with the salt dome structures prevalent in Gulf of Mexico oil fields. Almost overnight, this technology converted sulfur extraction from a labor-intensive gathering and purification process employing many persons to an industrial operation limited only by the size of equipment and deposit. The Frasch method of hydraulic mining with superheated water upended the Sicilian sulfur monopoly at the dawn of the Chemical Century. From 1905, when the island provided 95 percent of global supply, it fell to 50 percent by 1913 (Louisiana Geological Survey), on the verge of World War I's demand for gunpowder. The advent of Frasch sulfur shifted production across the Atlantic, where deposits were ideally suited to the new technology. The U.S. Gulf Coast, eventually including output in coastal Mexico, became the center of the Frasch sulfur industry until the late 1990s. Then, just as Frasch sulfur eliminated the Sicilian production monopoly, rising gas prices from US$0.25/MMBTU in the mid-1970s to more than $10/MMBTU in the early 1990 rendered the Frasch industry uneconomical, unable to compete with recovered sulfur extracted from natural gas and hydrocarbon fuels as a result of clean-air regulations.

Recovered sulfur, that associated with removal of elemental sulfur from natural gas and sulfur compounds present in crude oil and fuels, creates a large source of "waste." Whenever output exceeds demand it must be disposed-of, regardless of the cost. Volume gained momentum on the strength of air pollution and acid-rain environmental concerns, leading to the demise of U.S. and Mexican Frasch output by 2001. Today, Frasch mining is limited to Poland. The 2015 attempt to reopen Iraq's Mishraq mine was stymied by armed conflict.

Recovered sulfur (recovered/removed from natural gas and fuels), is the primary source of elemental sulfur supply. Of the almost 47 Mt (52 million st) sulfur output in 2011, less than 910 kt (1 million st) was Frasch (mined). This compares to at least 10 Mt (11 million st) extracted three decades prior (1981). Recovered sulfur output increased from 20 Mt/a to 45 Mt/a (22 million stpy to 49 million stpy) 132 percent during that period. World trade doubled from 15.6 Mt/a to 30.9 Mt/a (17.2 to 34 million stpy) during the period, as the geographic diversity of phosphate and sulfur producers widened (single continent North American sulfur and phosphate fertilizer production was partially supplanted by Arab Gulf/East Asia sulfur output and China/Morocco consumption).

North America did not experience a decline in sulfur production despite the collapse of its Frasch mining industry and extreme reductions at sour gas fields in Wyoming. Upgrading of Alberta's oil sands (heavy oil), and hydrocracking expansions implemented at many U.S. refineries to accommodate sour bituminous crudes from Alberta were counterbalancing developments.

The configuration of global sulfur output bears little resemblance to the 1980s when Frasch sulfur and Canadian gas were kings. Poland, the largest European Frasch producer 30 years ago has now closed all but one mine on energy costs and reduced reserves - the same fate that led to U.S. closures. It has retained a minuscule Frasch sulfur producer.

The Middle East now leads all producing regions. Abu Dhabi's Habshan and Shah gas fields, and others, have propelled the region into first place. Greater sulfur output is expected in coming years as sour gas fields in Saudi Arabia, Kazakhstan, Kyrgyzstan, Turkmenistan, Abu Dhabi, Iran, Qatar and others initiate startups, more sour crudes are refined and China continues aggressive oil and gas development. A note of caution regarding the forecasts: however, in this region, one almost always encounters delays. High temperature, pressure and hydrogen sulfide content create huge technical and operating challenges. Gas fields are deep and hot, with a very high content of hydrogen sulfide. An example, the Kashagan field in Kazakhstan, has now just started production and sales compared to a 2002 forecasted startup announced in 1990-1992. The third startup attempt apparently worked, possibly achieving an output rate of 1.8 Mt (2 million st)in 2019.

Another word of caution when estimating future sulfur supply is commercial availability. Many sourgas-linked sulfur extraction opportunities are very distant from markets leading to negative netbacks for sulfur output and producers stockpiling. Sulfur netbacks for processing of oil sand bitumen in Northeast Alberta have been negative for most of the last 24 months. Gas producers and refineries in those circumstances are left with two options: creating stranded stockpiles or pushing sulfur into a surplus market at a loss, often causing ever lower prices. Thus, availability of sulfur from distant locations is dependent upon stable prices at levels that can offer an adequate return on investments in infrastructure and transport expenditures. Yet the past decade has not seen the profitable and stable prices required to reliably bring new supplies to market.

Table 1

Elemental sulfur production and demand (Mt).

	2014	2015	2017	2020
World production	59.3	62.0	66.9	71.4
World demand	61.4	61.8	63.0	65.0
Balance	-2.1	0.2	2.3	6.4
Sources: IFA, Integer Research and Con-Sul Inc.				

The two most important global market-balancing considerations in 2017 are:

- Reduced production surrounding the startup of new sour gas fields in the Arab Gulf and South Asia ('Stans region) - their arrival has slipped from first quarter 2015-2016 into 2017.
- Reduced demand in almost all uses of sulfur. Fertilizer, metal ore leaching (from copper to nickel) and industrial uses have all continued to decline over the last two years.

The net effect should be a market balance shifting from deficit to a period of structural surplus lasting at least five and possibly 10 years. Notwithstanding, short term deficits will occur. Remaining long term inventories should be rebuilt to centralize disposal. To do so will require low prices and cooperation between government and industry. Without the leveling influence of commercially accessible inventory points, consumers will face highly volatile price conditions. Such a scenario has occurred repeatedly in the past, leading to wasted assets. We see little hope to change from this see-saw unless producers in the Arab Gulf adjust their operating philosophies.

As discussed in last year's issue, Mosaic Co.

Table 2

Principle regions of elemental sulfur production and forecast (000 t/a).

	2015	2018	2021	Change
Middle East	13.4	21.7	25.0	11.6
FSU	10.3	12.6	14.0	3.7
East Asia	10.0	11.9	13.0	3.0
North America	14.1	13.6	14.0	(0.1)
West Europe	3.8	3.9	3.9	0.1
Other	7.7	7.7	7.0	(0.7)
Total	59.3	71.4	76.9	17.6
Sources: IFA, Integer Research and Con-Sul Inc.				

has inaugurated a 1 Mt/a (1.1 million stpy) solid sulfur import and melting infrastructure in Florida. This to support 4 Mt/a (4.5 million stpy) of sulfur consumption. The infrastructure was built to diversify Mosaic's purchases into the international market. It will play a key role in restructuring and possibly destabilizing North American and world sulfur flows and prices.

How can such seemingly small changes in production, logistics or demand be so influential in a major raw material's market fluctuations?

Economists categorize sulfur as a price inelastic material, with certain additional peculiarities. Price inelasticity refers to the inability of low sulfur price leading to reduced output and increased consumption. Today sulfur is a material which is produced based on other product (hydrocarbon) economics and, as always, when buyers need sulfur they will pay any price. But, when sulfur is not needed by fertilizers or chemical companies, no amount of price decline can trigger demand. Maintaining the proper economic balance is almost

TALC AND PYROPHYLLITE

by G.P. Tomaino, Minerals Technologies Inc.

Talc is a layered, hydrous magnesium silicate mineral. It has a soft, soapy feel and typically a smooth texture and is known for its insulation, heat resistance, chemical stability, oil absorption and strong covering quality. Talc, $Mg_3Si_4O_{10}(OH)_2$, has a theoretical chemical composition of MgO at 31.7 percent, SiO_2 at 63.5 percent, and H_2O at 4.8 percent. However, talc's chemical and mineralogical composition can vary depending on its geological history/parent rock association. These mineral associations and variable levels are usually chlorite, quartz and carbonates (magnesite, calcite and dolomite). Two key elemental substitutions that can occur in the talc crystal structure are iron for magnesium and fluorine for hydroxyl. These compositional differences may limit or enhance the usage of talc in specific market niches. The United States, still, remains self-sufficient in most grades of talc.

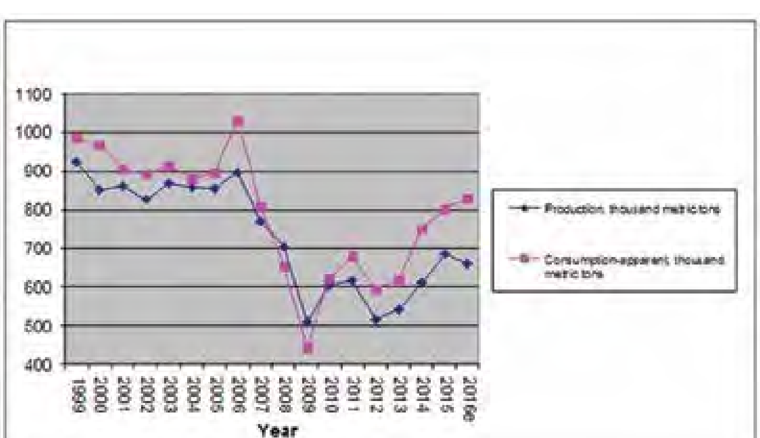
Talc deposits are categorized under four origin-types occurring as secondary and/or tertiary alterations of pre-existing rocks: 1) ultramafic 2) mafic 3) metasedimentary, and 4) metamorphic. Type 1 deposits while the most abundant are generally of lower grade and are second to Type 3 deposits based on utilization-commercialization. Type 4 deposits while historically a dominant source have diminished substantially in their usage over the years due to elevated amphibole content. Type 2 deposits are the least pure and utilized of all the origin-types. Another representation of the four talc origin categories noted above can be as ultramafic/mafic, metasedimentary-carbonate, metasedimentary-silicoaluminous and metamorphic.

Historically, product groupings such as industrial, cosmetic and pharmaceutical had inferred or denoted purity. However, in present times these groupings are no longer considered strict. Additional groupings of some talc products are categorized as chloritic-talc, carbonate-talc or tremolitic-talc. Here, the hyphened statements denote the second most dominant mineral phase (usually 20-50 percent) in addition to the predominant talc component (at 50 percent or greater).

Pyrophyllite is a layered hydrous aluminum silicate mineral. Pyrophyllite has similar physical properties as talc while elemental substitutions are minimal compared to talc. Pyrophyllite, $Al_2Si_4O_{10}(OH)_2$, has a theoretical chemical composition of Al_2O_3 at 28.3 percent, SiO_2 at 66.7 percent, and H_2O at 5 percent. Typical accessory minerals can be quartz, kaolin, diaspore, boehmite, sericite and chlorite, in addition to iron-containing impurities of hematite, limonite/goethite and pyrite. Grades are differentiated by particle size, moisture content, fired color and purity as measured by fineness and screen residue. Pyrophyllite deposits are generally classified under hydrothermal or metamorphic with more expanded types as: 1) hydrothermal in metasomatites continental and island-arc volcanic zones, platforms, folded systems 2) hydrothermal in metasomatites in wall rock quartz veins-granitoids and metamorphosed clastic suites 3) metamorphosed metasomatites in submarine volcanic zones enclosing sulfide ores 4) stratiform metamorphosed clastic clay suites with pyroclastic material and coal seams and 5) in clays formed by

Figure 1

18-year trend data for talc production (kt) and consumption (kt), 1999 to 2016e.



weathering. Pyrophyllite has a high dielectric strength, low electrical conductivity, reasonably high thermal stability and chemical inertness that allows for primary usages in refractory and ceramic applications. Critical attributes in refractory applications are iron and quartz content while a critical attribute in ceramics is whiteness before and after firing. Additional industrial usages are in paint, chemical carriers in agricultural, and filler in industrial coatings, sealants and caulks.

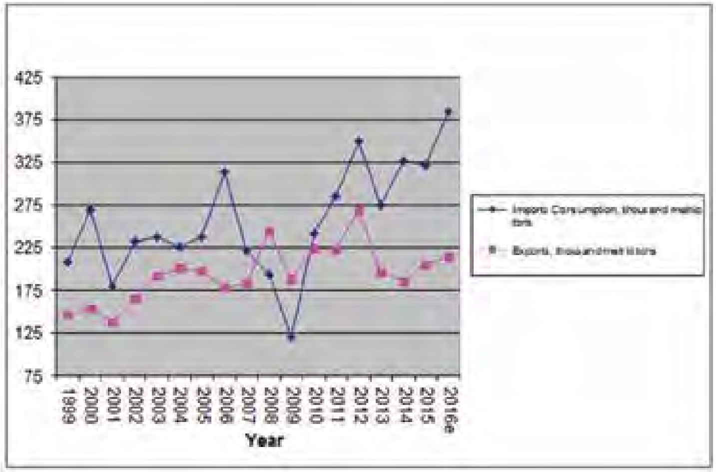
Production and consumption

For 2016, the primary producer of pyrophyllite in the United States and with worldwide distribution is Vanderbilt Minerals, LLC – Standard Mineral Division (owned by R.T. Vanderbilt) in North Carolina. The parent company celebrated its 100 year anniversary in 2016. The division owns more than 607 ha (1,500 acres) of land that have reserves in excess of 100 years. Pyrophyllite ore is mined in several openpit mines and is crushed, dry-ground and air-classified at the division's mill in Robbins. The processed pyrophyllite ore is sold under the trade name PYRAX. Piedmont Minerals also in North Carolina supplies product but mainly for in-house usage with its parent company, RESCO. Domestically, pyrophyllite production increased from 2015 with consumption in decreasing order of refractory, ceramics and paint. Employment in domestic pyrophyllite operations has increased slightly over the last four years from 23 to 30 (2016e). For North America, Trinity Resources has mining, production and port facilities located in Labrador. Trinity Resources sells and distributes pyrophyllite products under the Altifil, Altiplus and Altiblock trade names with usage in refractory, automotive, plastics, paints, paper coatings and cosmetics.

In 2016, it is estimated that three talc companies operated five talc mines and production facilities located in three states accounting for 99 percent of domestic production. Domestic production is basically openpit mining. Montana continues to be the leading state for production followed by Texas and Vermont. Imerys Talc remains the top domestic and international talc producer with domestic mines and processing facilities in Montana and Vermont and with processing in Texas in addition to operations in Canada, Australia, China and Japan. Minerals Technologies Inc. through its Barretts Minerals, a subsidiary of Specialty Minerals Inc. has mining and processing in Montana and processing in Texas. CIMBAR Performance Minerals conducts processing of imported talc in Indiana, Ohio and Texas in addition to operating facilities in China and Pakistan. American Talc Company has mining and processing in Texas. IMI FABI has processing plants for imported talc in West Virginia and New York in addition to operations in Italy, Australia, Pakistan and China. Alberene Soapstone Company operates in Virginia and Southern Oregon Soapstone Company LLC operates in Oregon.

Figure 2

18-year trend data for import consumption (kt) and exports (kt), 1999-2016e.



Previously reported 2015e (2015 estimated) production and consumption values have been corrected with 2015 actual values in the 18-year trend figures. In the past three years, talc production has been trending upward and has surpassed previous 2009 levels but is still below 2006 highs for the industry. For 2016e, talc production was estimated at 660 kt (727,000 st), talc sold by the producers which included domestic and exports was at 545 kt (600,000 st) estimated a decrease of only about 1 percent from 2015 levels and was valued at $98 million.

For 2016e, apparent consumption of talc was at 830 kt (914,000 st) estimated an increase of approximately 3.5 percent from 2015 levels. The 2016e average-price for a processed ton of product with an averaged pricing was at approximately $180/t ($163/st) and was an increase of approximately 6.5 percent from 2015e. The 18-year trend data for production and apparent consumption from the USGS are provided in Fig. 1.

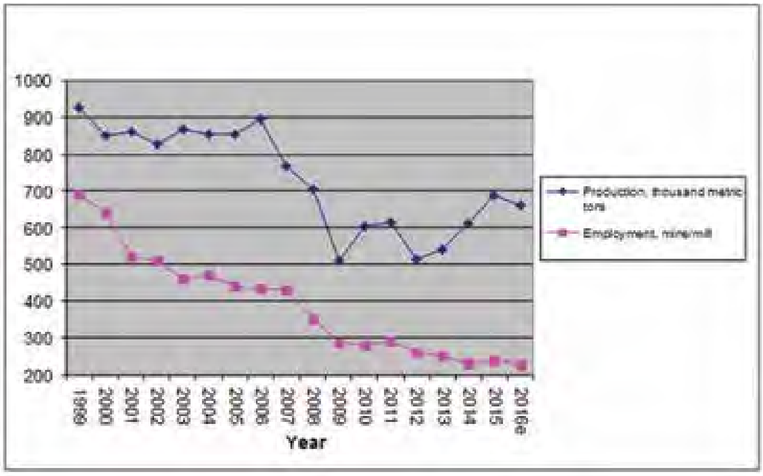
Talc produced and sold domestically had distributions as follows: ceramics (26 percent), paper (18 percent), paint (17 percent), roofing (7 percent), plastics (12 percent), rubber (4 percent), cosmetics (3 percent) and other (13 percent). The ceramic sector is dominated by catalytic converter usage a key component of the formulation. The "other" section includes a variety of applications for pharmaceuticals, agricultural products, animal-feed, sealant, sculpturing, food and polishing.

Exports/imports

The 2016 estimated (2016e) talc exports were at 215 kt (237,000 st), an increase of 4 percent from 2015 actual at 206 kt (227,000 st) but still significantly less than 2012 at 270 kt (297,000 st). For the last three years, Canada and Mexico accounted for 70 percent of the export usages. The 2016 estimated (2016e) talc imports were at 385 kt (424,000 st), a substantial increase of 20 percent from 2015 at 322 kt (355,000 st) and higher than the historical high of 350 kt (385,000 st) in 2012. As presented by USGS and sourced from the U.S.

Figure 3

18-year trend data for talc production (kt) and employment, 1999-2016e.



Census Bureau, 95 percent of imported talc sourced from China (34 percent), Pakistan (34 percent) and Canada (26 percent) where volumes from China and Pakistan increased by 42 percent and 15 percent, respectively. Imported talc usage was in various applications of cosmetics, paints, and plastics with remaining usage under ceramics, paper, roofing and rubber. For Pakistan, USGS reported large quantities of crude talc mined in Afghanistan was milled in and exported from Pakistan. Eighteen-year trend data of imports for consumption and exports taken from the USGS are provided in Fig. 2.

Over the last seven years (2009-2016e), talc sector employment continued its decrease as 2016 estimated and 2015 employment levels at mines and mills were at 225 when compared to recent highs of 325 [1] in 2008. An important note to the talc employment overview is that historically, pyrophyllite mine employment was included under talc mine employment. Pyrophyllite mine employment ranged from 25 to 30 over 2012-2016e and have been adjusted in the 18-year trend data of production (kMT) and employment from USGS in Fig. 3.

Uses, new applications, processing technology, future trends

Talc producers must continue to provide a functional and high performance mineral additive that can increase the value of their products to the end use customer. In specific cases, unique properties can be achieved by employing proprietary coatings or processing products to increase aspect ratio by delaminating (HAR grades) or to increase the overall talc purity by beneficiation. Silane/siloxane based and directed surface treatments are commonplace. Nano-talc products (10 to 100 nanometers in one dimension) continue to be researched and marketed for their uses in various applications. Talc usage covers a multitude of product categories: plastics, cosmetics, flooring, health care, catalytic converters, animal feed, caulks, sealants, gaskets, belts, hoses, specialty anti-blocking/anti-hazing in plastic films, auto body putty, asphalt shingles, joint compounds, pharmaceuticals, ceramics and dimension stone.

In cosmetics, talc competes against corn starched products. In ceramic applications of dinnerware, sanitary ware, and hobby ceramics, talc provides low shrinkage as well as high brightness upon firing at various temperatures. In other applications, high quality calcined-talc blends can be tailored to individual customer's specifications to impart a controlled shrinkage and reduce firing time. The reduced firing time aids in processing and energy costs for the customer. Another specialty usage for which demand remains high for talc is combining talc with kaolinite and other proprietary additives to formulate fired-cordierite bodies used for catalytic converters for vehicles. The competitive products in this field are SiC or metal-based catalytic converters. In dimension stone applications, talc is used for countertops, sinks, mantels, fireplace surrounds, pavers, and tile brick. In paints, talc is an economic extender and filler while providing brightness and durability to paint coatings. In rubber applications, talc provides reinforcement, UV radiation resistance, and can be used as a processing aid for good extrusion rates, impermeability and improved surface finish. However, more and more paints are shifting to water based matrices from oil-based matrices to reduce organic volatiles; talc being hydrophobic in nature loses opportunities in these market-product shifts.

The plastics market continues to offer some potential growth opportunities especially in polypropylene. It is projected that increases in talc usage for lightweight and recyclable product are needed for the automotive market. Here, the desire for compacted and sub-micron talc products provide high performance end use products.

Talc continues to be used in the paper making process especially as a pitch control agent while it faces competition in the paper filler and niche paper coating sectors from precipitated and ground calcium carbonates. In ceramics, talc competes with clays and pyrophyllite; in paint, plastics, and rubber with kaolin and mica.

Substitutes for talc in ceramics are bentonite, chlorite, kaolin and pyrophyllite; in paint are chlorite, kaolin, and mica; in paper are calcium carbonate and kaolin; in plastics are bentonite, kaolin, mica and wollastonite; and in rubber are kaolin and mica.

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[1] Prior to 2012, pyrophyllite mine employment was apparently included under talc mine employment. Pyrophyllite mine employment ranged from 25 up to 30 over 2012-2016e and have been adjusted to the talc mine employment data in the 18-year trend figure.

Environmental and regulatory

As reported in two previous annual reviews, the talc industry had been working on responding to Canada's Health Canada and Environment Canada on the Domestic Substances List Inventory Update Phase 2 through its Chemicals Management Plan as to whether talc should be classified as an environmental toxin. In September 2015 and 2016, industry representatives, consultants, and IMA-NA staff finalized and presented a concise and informative presentation to Canadian authorities and continue to work on finalizing their work.

Under United States Pharmacopeia (USP), a second USP Expert Panel-Talc 2015-2020 has been convened with representation from industry, contract testing laboratories, academia and USP and has been working diligently on improving the talc monograph attribute for Absence of Asbestos testing for pharmaceutical grade talcs.

As noted in last year's annual review, talc continues to receive negative press coverage on two fronts through various articles and litigation notices of talcum powder usage and ovarian cancer linkage; and also talcum powder, purported to contain asbestos, body usage for many years linked to mesothelioma cases. For 2016, in several Johnson and Johnson litigations under the talc-ovarian cancer linkage both sides have seen favorable verdicts with cases continuing into 2017. ■

TITANIUM AND TITANIUM MINERALS

by George M. Bedinger, National Minerals Information Center, U.S. Geological Survey

Titanium is the ninth most abundant element in the earth's crust and can be found in nearly all rocks and sediments. It is a lithophile element with a strong affinity for oxygen and is not found as a pure metal in nature. Titanium was first isolated as a pure metal in 1910, but it was not until 1948 that metal was produced commercially using the Kroll process (named after its developer, William Kroll) to reduce titanium tetrachloride with magnesium to produce titanium metal.

Ilmenite ($FeTiO_3$) and rutile (TiO_2) are the two principal minerals used as the source for TiO_2 pigments and titanium metal. All of the world's natural rutile and a significant proportion of the world's ilmenite are currently mined from placer deposits. Ilmenite is also mined from hard-rock deposits in Canada, China, Norway and Russia. In addition to their use as feedstock for TiO_2 pigments and titanium metal, titanium minerals also are used for a variety of applications including abrasives, metallurgical fluxes, welding-rod coatings and other titanium-based chemicals.

For placer deposits, dredging and dry mining surface techniques are used for the recovery of titanium minerals. Gravity spirals, magnetic and high-tension separation circuits are used to separate the heavy mineral sands. Ilmenite is often processed to produce a synthetic rutile or titaniferous slag. Although numerous technologies are used to produce synthetic rutile, nearly all are based on either selective leaching or thermal reduction of iron and impurities in ilmenite. Titaniferous slag containing 75 percent to 95 percent TiO_2 is produced commercially using pyrometallurgical processes.

TiO_2 pigment is produced from ilmenite, rutile or titaniferous slag by either the chloride process or the sulfate process. The sulfate process uses simpler technology than the chloride process and can use lower-grade, less-expensive feedstock, but may have higher infrastructure and process costs. Pigment produced by either process is categorized by crystal

Table 1

World: Ilmenite and rutile production (data in kt of contained TiO_2).

Country	2013	2014	2015	2016[e]
Australia	1,380	910	1,100	1,070
Canada	770	480	595	475
China	1,020	960	850	800
India	364	207	198	218
Kenya	-	122	338	360
Madagascar	272	309	145	145
Mozambique	430	510	460	490
Norway	498	440	258	260
Senegal	-	60	257	260
Sierra Leone	81	100	113	120
South Africa	1,250	653	1,350	1,370
Ukraine	200	313	465	440
United States[1]	200	100	200	100
Vietnam	720	560	360	300
Other countries	214	317	255	195
Total (rounded)	7,400	6,040	6,940	6,600

Source: U.S. Geological Survey
[e] Estimated production.
[1] Rounded to one significant digit to avoid disclosing company proprietary data.

Industrial Minerals

Figure 1

Average quarterly prices for ilmenite, rutile, and titanium dioxide (TiO_2) pigments, from 2010 through 2016; f.o.b. Source: Industrial Minerals, U.S. Census Bureau.

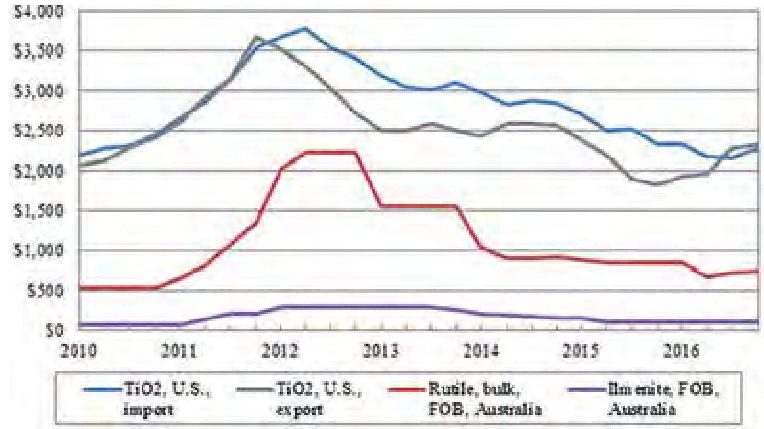
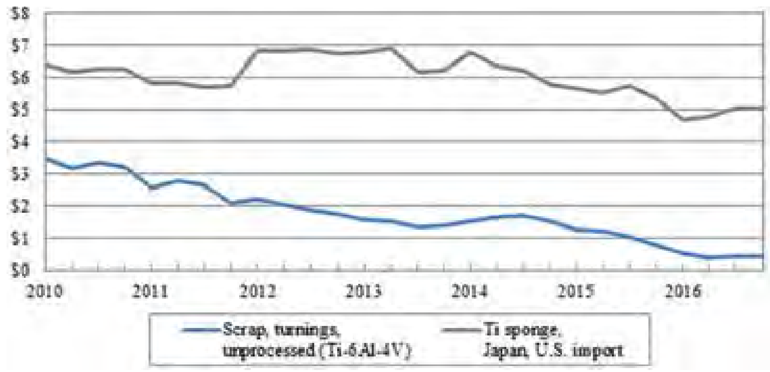


Figure 2

Average quarterly prices for titanium metal sponge and titanium scrap from 2010 through 2016. Source: Platts Metals Week, U.S. Census Bureau.



form as either anatase or rutile (polymorphs of TiO_2). Depending on the manner in which it is produced and subsequently finished, titanium dioxide pigment can exhibit a range of functional properties, including dispersion, durability, opacity and tinting. About 90 percent of global titanium mineral consumption is for the production of TiO_2 pigments.

Production

Global production of titanium concentrates was estimated to be 6.6 Mt (7.3 million st) of contained TiO_2 in 2016, a decrease of 5 percent from that of 2015 (Table 1). Global reserves of ilmenite were 770 Mt (848 million st) of contained TiO_2 and those of rutile were 59 Mt (65 million st) of contained TiO_2. Rounded to one significant digit, U.S. production of titanium concentrates was estimated to be 100 kt (110,000 st) of contained TiO_2. TiO_2 pigment production in the United States in 2016 was estimated to be 1.2 Mt (1.3 million st), a slight decrease from that of 2015, with domestic consumption estimated to have been 771 kt (850,000 st), a 3 percent decrease from that in 2015. Global titanium metal sponge production in 2015 (Table 2), excluding the United States where production data were withheld to avoid disclosing company proprietary data, was estimated to have increased by 6 percent from that of 2015 to 170 kt (187,000 st). In 2016, U.S titanium sponge capacity remained at 24 kt/a (26,000 stpy). Domestic consumption reported by the titanium metal industry was 34 kt (37,500 st).

Foreign trade

In 2016, the United States was 91 percent import reliant for titanium mineral concentrates and imported about 970 kt (1 million st) of contained TiO_2 in titanium concentrates. The leading import sources were, in decreasing order, South Africa, Australia, Canada and Mozambique. The United States was 45 percent import reliant for titanium metal sponge and imported 16.2 kt (17,800 st) of sponge in 2016. The leading import source was Japan, which accounted for 98 percent of imports. Although imports from Japan in 2016 were almost identical with those of the previous year, imports from China, Kazakhstan and Ukraine decreased significantly, possibly owing to the termination of sales contracts and continued low prices for titanium sponge and scrap. In 2016, the United States was a net exporter of TiO_2 pigments, with 58 percent of these exports going to China and Canada.

Prices

Prices for ilmenite and rutile were lower at yearend 2016 than they were the previous year. TiO_2 pigment prices for imports into the United States decreased during most of 2016 from an average of $2,319/t ($2,103/st) in the first quarter to $2,150/t ($1,950/st) in the third quarter, before increasing by 6 percent to $2,270/t ($2,059/st) in the fourth quarter. Export prices for TiO_2 pigment generally rose during 2016 from an average of $1,928/t ($1,749/st) in the first quarter to $2,334/t ($2,117/st) in the fourth quarter (Fig. 1). Titanium sponge metal and scrap posted lower yearend prices in 2016 than those in 2015 as a result of continued high sponge and scrap inventory levels at titanium mill operations (Fig. 2).

Industry news

Tronox Ltd. (Stamford, CT) began production at its Fairbreeze Mine in South Africa in late 2015, and officially opened the mine in April 2016. Fairbreeze was developed as a replacement for the Hillendale Mine, which closed in early 2014. The Fairbreeze Mine was expected to produce 450 kt/a (496,000 stpy) of ilmenite and 25 kt/a (27,500 stpy) of rutile during a mine life of more than 12 years based on current reserves. In December, Iluka Resources Ltd. (Perth, Australia) completed its acquisition of Sierra Rutile Ltd. (Freetown, Sierra Leone), positioning Iluka as the leading global producer of rutile. Sierra Rutile is the only large-scale, high-grade primary rutile mine in the world with an estimated mine life of more than 18 years based on current rutile reserves.

The Chemours Co. announced the startup of its new 200 kt/a (220,000 stpy) TiO_2 production line in Altamira, Mexico, in May. The rampup to full capacity was expected to take several years and was intended to offset the loss of production when Chemours closed its TiO_2 plant in Edgemoor, DE, and reduced production at its New Johnsonville, TN, facility, both in 2015.

Huntsman International LLC (The Woodlands, TX) announced the divestiture and spinoff of its TiO_2 operations. The new company was to be named the Venator Materials Corp. and was expected to trade on the New York Stock Exchange in the second quarter of 2017. Huntsman also closed its TiO_2 pigment plant in Umbogintwini, South Africa, in December 2016 owing to the age of the plant and low profit margins.

In February 2017, Tronox announced an agreement to acquire The National Titanium Dioxide Company Ltd. (Cristal) (Jeddah, Saudi Arabia), which included eight titanium dioxide plants, six mineral sands mines, and associated mineral processing plants. Tronox also intended to acquire Cristal's titanium slag facility being commissioned in Jazan, Saudi Arabia, but the inclusion was still under negotiations. If the agreement was approved by shareholders and met regulatory approval, the combined company would become the largest global producer of titanium pigments with a capacity of 1.33 Mt/a (1.46 million stpy) and could produce about 15 percent of the world's titanium concentrates, which would be integrated into its pigment production. The acquisition was expected to be completed by the first quarter of 2018.

In August, Allegheny Technologies Inc., (ATI), announced that it would idle its Rowley, UT, titanium sponge facility by the end of 2016 and consolidate certain titanium operations in Albany, OR. According to ATI, significant global titanium sponge capacity added in recent years and weak demand for industrial-grade titanium allowed it to secure aerospace quality sponge under long-term supply agreements at prices lower than production costs at its Rowley facility. The facility was to be idled in a manner that would allow it to be restarted if supported by market conditions.

Table 2

World: Titanium sponge metal production (data in kt).

Country	2013	2014	2015	2016[e]
China	105	110	62	60
India	0	0.5	0.5	0.5
Japan	42	25	42	54
Kazakhstan	12	9	9	9
Russia	44	42	40	38
United States	W	W	W	W
Ukraine	6.3	7.2	7.7	7.5
Total (rounded)[1]	209	194	160	170

Source: U.S. Geological Survey
[e] Estimated production.
W Withheld to avoid disclosing company proprietary data.
[1] Excludes U.S. production.

Outlook

Because TiO_2 pigment is used in paint, paper and plastics, consumption is generally tied to economic growth. In January 2017, the International Monetary Fund forecast global economic growth to be 3.4 percent for 2017, with China's growth forecast at 6.5 percent. TZ Minerals International, an independent consulting company for the titanium industry, expected an increase in feedstock production, assisted by the restart of titanium slag operations at TiZir Ltd. in Norway and higher utilization rates of same in South Africa. Furthermore, Iluka, one of the leading global producers of titanium concentrates, had drawn down its feedstock inventories in anticipation of an increase in pigment production in 2017. The titanium sponge market remained oversupplied in 2016, with a global production utilization rate at about 60 percent of capacity. Sponge inventories in the United States remained at high levels. According to Ust-Kamenogorsk Titanium and Magnesium Plant Joint Stock Co. (Ust-Kamenogorsk, Kazakhstan), the low cost of sponge compared to that of scrap, along with increased integration of scrap in the titanium supply chain, was likely to be a major factor in sponge inventories remaining high for several more years. ■

VANADIUM

by D.E. Polyak, National Minerals Information Center, U.S. Geological Survey.

In 2016, the United States continued to be a major producer of vanadium products from secondary sources. Six companies in the United States comprised most of the domestic vanadium industry. These companies produced ferrovanadium, vanadium pentoxide, vanadium metal and vanadium-bearing chemicals or specialty alloys by processing secondary materials such as petroleum residues, spent catalysts, utility ash and vanadium-bearing pig iron slag. From 2009–2013, small quantities of vanadium were produced as a byproduct from the mining of uraniferous sandstones on the Colorado Plateau. However, all byproduct vanadium production in the United States was suspended in 2014.

Production

Vanadium is extracted from vanadiferous ores, slags and residues and converted into vanadium pentoxide or trioxide. Most vanadium pentoxide is converted into ferrovanadium. A majority of the world's supply of vanadium was derived from mined ore, either directly from mineral concentrates derived from vanadiferous titanomagnetite (VTM) or from steelmaking slags, where the steel was produced from VTM. Japan and the United States were thought to be the only countries to recover significant quantities of vanadium from petroleum residues. The leading vanadium-producing nations (from ore, concentrate and slag) in 2016 were China (55 percent), Russia (21 percent) and South Africa (16 percent).

Consumption

Vanadium's primary use is as a hardening agent in steel, in which it is critical for imparting strength, toughness and wear resistance. These properties are especially important in high-strength low-alloy (HSLA) steels. In 2016, production of carbon, full-alloy and high-strength low-alloy steels accounted for 16 percent, 44 percent and 36 percent, respectively, of domestic reported consumption. Nonmetallurgical applications included catalysts, ceramics, electronics and vanadium chemicals. Catalysts were the leading nonmetallurgical use for vanadium.

Prices

In 2016, the average monthly price for domestic ferrovanadium, as published by CRU Group, ranged from $5.95 to $11.52/lb of vanadium content. In 2016, the average monthly price for domestic vanadium pentoxide published by CRU Group ranged from $2.785 to $4.65/lb of vanadium content in 2016.

Foreign trade

In 2016, the United States imported (measured in vanadium content) 2.2 kt (2,400 st) of ferrovanadium, 2.5 kt (2,750 st) of vanadium pentoxide, and 660 t (727 st) of other oxides and hydroxides of vanadium. Total imports for consumption of all vanadium-bearing materials decreased by 26 percent from those of 2015. In 2016, the United States exported (measured in vanadium content) 533 t (587 st) of ferrovanadium, 10 t (11 st) of vanadium pentoxide, and 117 t (129 st) of other oxides and hydroxides of vanadium. Total exports of all vanadium bearing materials decreased by 25 percent from those of 2015.

Outlook

Owing to the fact that almost all vanadium is consumed in the production of steel, consumption trends are greatly influenced by trends in steel production; the range of steel grades that contain vanadium has continued to increase. The outlook for demand in nonferrous alloys is largely dependent on trends in demand for titanium alloys in business, commercial and military aircrafts. One area of growth is in the energy storage market, specifically with the vanadium redox battery (VRB). The VRB consists of an assembly of power cells in which two vanadium-based electrolytes are separated by a proton exchange membrane. Many countries are seeking to meet renewable energy targets by 2030 or earlier and VRB storage is proving to be a viable answer, with many countries having numerous implementations already underway. However, the high cost of the electrolyte used in the VRBs and the system complexity of the batteries may be difficult to overcome. ■

VERMICULITE

by Eric Moeller, Nanoparticle Consultancy LC

Worldwide vermiculite usage in 2016 is estimated at 493 kt (543,000 st)), which is a 3.7 percent decrease from 2015. For more than 20 years the annual volume has centered around 500 kt/a (550,000 stpy).

Vermiculite is mined from shallow (less than 35 m or 114 ft) surface deposits throughout the world, as all commercial vermiculite is formed by surface weathering of either biotite or phlogopite micas. Processing is via air winnowing, or wet gravity separation followed by drying and final screening, producing a vermiculite concentrate of approximately 90+ percent purity. The concentrates are then sold and used as intumescent coatings and other fire protection products. Or they will be exfoliated (expanded through steam formation from the interstitial water trapped in the silicate layers in ovens reaching 800 to 1,000 °C or 1,475 to 1,830 °F) by either vertically integrated expanders or independent expanders. The exfoliated vermiculite is very light weight, a thermal insulator, highly absorbent and non-reactive (except to extremely strong acids). A small amount of vermiculite concentrate is also chemically delaminated to produce an aqueous based dispersion, which is then applied as a coating, providing anisotropic characteristics as well as high gas barrier properties.

North American production was essentially flat in 2016 (slightly more than 100 kt (110,000 st) in 2016) from two mining companies: Virginia Vermiculite Ltd, Louisa, VA and Specialty Vermiculite Corp., Enoree, SC. Both mines produce vermiculite from biotite micas producing finer sizes (less than 2 mm). Very little vermiculite is exported from North America (just a few hundred metric tons), and imports are mostly larger sizes of concentrate, primarily from South Africa.

Outside of North America the major producers include the following: Hebei Iron & Steel Group with its mine Palabora Mining Company, Ltd., Phalabowra, South Africa (ore stock is phlogopite mica, 2016 production estimated at 170 kt (187,000 st), making this the largest mine in the world); Xinlong Vermiculite, Korla, China (biotite mica ore stock); and Brasil Minerios (ore stock is biotite mica), with mines in Goias, Brazil and a plant in Sao Luiz. Brasil Minerios has been expanding its mining operations (estimated production of 70 kt or 77,000 st in 2016) for several years with a goal of 200 kt/a (220,000 stpy). Smaller mining companies operating in Russia, India, Australia, Africa, India and China also produced vermiculite concentrates.

Imerys Industrial Minerals, Paris, France, had intermittent mining at its Samrec Vermiculite Ltd., Zimbabwe (Shawa deposit), with political and logistics issues hampering production. Wolf-Mueller Minerals had limited production at its Verona mine in Bulgaria. In early 2016 Black Mountain Resources, Ltd, Australia, acquired the Namakera vermiculite and Busumbu phosphate project in Uganda from Africa Phosphate Pty, Ltd. with production capacity estimated at 30 kt/a (33,000 stpy). Export sales from this mine were confirmed in early 2017.

Primary uses for expanded vermiculite are in horticultural (potting soils and amendments for exfoliated vermiculite) and fire protection applications (fire protection sprays, boards and ceramics), which are by far the largest markets. In addition smaller quantities are used in packaging, specialty concretes, pollution and wastewater treatment. Vermiculite concentrate markets are primarily fire protection products and feedstock for dispersion markets, with small amounts used in metal casting toppings and pollution control.

Prices for domestic U.S. vermiculite concentrate, ex-plant, ranged from \$140 to \$575/t (\$127 to \$530/st) depending on grade size, unchanged from 2015. Imports into the United States for vermiculite concentrate, bulk, f.o.b. barge, Gulf Coast port ranged from \$280 to \$1,100/t (\$254 to \$997/st). Generally, pricing is dependent on particle size and yield (thermal expansion) - the greater these values the higher the price. North American producers do not have coarser, higher yielding deposits, so all of this concentrate must be imported (mostly from South Africa and China). Pricing in U.S. dollars was essentially flat in 2016, due to the increase in the value of the U.S. dollar.

Total worldwide production capacity continues to outpace consumption, but the coarser size (greater than 2 mm particle) products are in very constrained supply, while the very fine sizes are in excess capacity. This has been the case for several decades. ■

WOLLASTONITE

by Madan M. Singh, National Minerals Information Center, U.S. Geological Survey

Wollastonite is a calcium metasilicate with the chemical formula $CaSiO_3$. It is a member of the pyroxenoid group of minerals, ideally with the composition of CaO 48.3 percent and SiO_2 51.7 percent. It may contain trace to minor amounts of aluminum, iron, magnesium, manganese, potassium, sodium or strontium substituting for calcium. It is usually white but also may be gray, cream, brown, pale green or red depending on the impurities and grain size.

Two types of deposits are known — skarn deposits (thermal metamorphic and metasomatic) and carbonatites (magmatic). Associated minerals include calcite, diopside, epidote, garnet, plagioclase feldspar, pyroxene, tremolite and vesuvianite.

The mineralogy of the wollastonite determines whether the mineral can produce a high-purity concentrate. The concentrate should contain about 97 percent wollastonite. Governing factors include the constituents of the gangue, grain size and the amount of intergrowth of the minerals. Garnet and diopside are commonly found with the wollastonite and need to be removed by high-intensity magnetic separators. Calcium carbonate is removed by flotation. Minor amounts of other minerals, generally less than 0.5 percent, do not affect the performance characteristics and do not need to be removed. Processing may be dry or wet.

Synthetic wollastonite is produced in very small quantities, less than 2 percent of world production. This is normally not acicular, although some very fine fiber wollastonite is produced in Japan. Other countries where synthetic wollastonite has been made include Brazil, Denmark, Germany, Italy and the United States. However, most of these are hydrous, have high absorptivity and lack acicular shape.

Wollastonite is used as a substitute for short-fiber asbestos, and its use has increased significantly from the 1950s to the present. The major uses of wollastonite include plastics and ceramics.

Production

In 2016, only two companies mined wollastonite in the United States. NYCO Minerals, Inc. (a subsidiary of Imerys S.A., France) operated a mine and processing plant near Willsboro in Essex County, NY. The NYCO deposit contains diopside and garnet, which are removed using high-intensity magnetic separators, and up to 60 percent wollastonite. Vanderbilt Minerals, LLC (a division of R.T. Vanderbilt Holding Co., Inc.) operated a mine and processing plant near Balmat in Lewis County, NY. The Vanderbilt Minerals deposit is highly differentiated, with large regions of wollastonite separated from gangue zones, and consists primarily of wollastonite (up to 90 percent) and minor amounts of calcite, diopside and prehnite. The production figures for NYCO and Vanderbilt are withheld to avoid disclosing company proprietary data.

Consumption

The U.S. Geological Survey does not collect consumption statistics for wollastonite, but consumption was estimated to have decreased in 2016 compared to that in the previous year. U.S. single family housing starts in 2016 were 9 percent higher in 2017 compared to 2016, suggesting that sales of wollastonite to domestic construction-related markets, such as adhesives, caulks, cement board, ceramic tile, paints, stucco and wallboard, might have increased. Trends in other domestic manufacturing sectors that use wollastonite were mixed; production of plastics and rubber and primary iron and steel products declined slightly, whereas output of motor vehicles and parts (which contain wollastonite in friction products and plastic and rubber components) rose by nearly 5 percent. In Western Europe and Asia, demand for wollastonite likely remained relatively unchanged owing to minimal growth in construction and manufacturing.

Plastics and rubber markets (thermoplastic and thermoset resins and elastomer compounds) were estimated to account for more than 25 percent of wollastonite sales in the United States, followed by ceramics (frits, sanitaryware and tile), paint (architectural and industrial paints), metallurgical applications (flux and conditioner), friction products (primarily brake linings), and miscellaneous uses (including adhesives, concrete, glass and sealants). Globally, ceramics were estimated to represent more than 30 percent of wollastonite sales, followed by polymers (such as plastics and rubber) and paint. Lesser global uses for wollastonite included miscellaneous construction products, friction materials, metallurgical applications and paper.

Prices

At yearend 2016, reported prices for domestically produced acicular wollastonite, ex-works, were $231 to $265/t ($209 to $240/st) for 200-mesh, $243 to $276/t ($220 to $250/st) for 325-mesh and $485 to $491/t ($440 to $445/st) for wollastonite with an aspect ratio of 15:1 to 20:1. Prices for wollastonite from China in bulk, free on board (f.o.b.), were $88 to $110/t ($80 to $100/st) for 200-mesh and $99 to $116/t ($90 to $105/st) for 325-mesh. Domestic prices remained unchanged from 2015, but those from China increased slightly from the year earlier. Quoted prices should be used only as a guideline because actual prices depend on the terms of the contract between seller and buyer.

Foreign trade

In 2016, exports were estimated to have decreased and imports were estimated to have increased. Most of the trade was with Canada and Mexico by road or rail. It is estimated that less than 10 kt (11,000 st) of wollastonite was exported and nearly 4 kt (4,400 st) was imported. Comprehensive trade data were not available for wollastonite because it is imported and exported under a generic U.S. Census Bureau Harmonized Tariff Schedule code that includes multiple mineral commodities.

Outlook

According to the International Monetary Fund global growth slowed to 3.1 percent in 2016 but is expected to grow at 3.4 percent in 2017.

The U.S. Census Bureau projects that the value of construction in the United States in 2016 was 4.5 percent higher than that of 2015 and is projected to continue to grow in 2017. This suggests that sales of wollastonite may rise for construction-related products, friction products, plastics and rubber. ■

ZEOLITES

by Daniel T. Eyde, St. Cloud Mining

The U.S. Geological Survey (USGS) estimates world production of natural zeolites as relatively unchanged at 2.8 Mt (3.1 million st) in 2016. China continues to be ranked first with production estimated in the range of 2 Mt (2.2 million st), followed by the remaining significant producers including the Republic of Korea, 205 kt (225,500 st); the United States, 80 kt (88,000 st); New Zealand, 80 kt (88,000 st); Turkey, 60 kt (66,000 st); Cuba, 51 kt (56,100 st); Jordan, 12 kt (13,200 st) and all other countries at 350 kt (385,000 st).

There are a number of other countries producing zeolites in the Mediterranean and Eastern Europe, but production statistics are not available. Turkish and Jordanian production is estimated to be down somewhat from 2015 levels, while New Zealand and Cuba are projected upward. In China and other countries, high-volume low-value construction applications (which include dimension stone, pozzolans and lightweight aggregate) are also included in production. This means that the production data does not accurately indicate the quantities used in high-added-value specialty applications like water treatment or consumer products.

Production in the United States grew again in

2016 from 75.1 kt (82,600 st) to 80 kt (88,000 st), according to preliminary USGS statistics. New Mexico was the leading producer of natural zeolites in 2016 followed by Texas, Idaho, California, Oregon and Arizona. Domestic uses for natural zeolites were (in decreasing order by tonnage): animal feed, water purification/treatment, odor control, unclassified other, oil and grease absorbents, fungicide or pesticide carriers, pet litter, wastewater cleanup, gas absorbent, fertilizer carrier, desiccants, soil amendment, miscellaneous sorbent, synthetic turf, aquaculture and desiccants. The three leading uses accounted for more than 75 percent of the domestic natural zeolite sales tonnage.

Import/export

The United States is not a significant importer of natural zeolites. Although, with the possible opening of trade between the United States. and Cuba, this has the potential to change. There is significant zeolite production in Cuba from deposits of high purity clinoptilolite that have been exploited on an industrial scale in the past primarily for pozzolanic applications. Much of this production appears to be used in South America or domestically. The United States does export high-added-value processed and activated chabazite products for gas adsorption and ion exchange applications. There is a growing market for specialty feed products as well.

Prices

Clinoptilolite remains the primary product at more than 90 percent of U.S. production. Chabazite remained at about 7-8 percent of production in 2016, with the remainder principally mordenite. Both phillipsite and ferrierrite are now available in limited quantities. However, if the products were examined on the basis of finished manufactured products, then much of the zeolite total mined sales value is a result of chabazite sales of specialty ion exchange and sorption products.

Prices are based on the percentage of the zeolite and accessory minerals in the product, its chemical and physical properties as well as its particle size. The price of zeolite products are reported f.o.b. mine in bulk at $110 to $950/t ($121 to 1,045/st) by the USGS in 2016. Generally, granular products carry a premium, particularly for water treatment products that must carry an NSF certification. Products for pool filtration are significantly higher than f.o.b. mine costs due to distribution, packaging, marketing and certification expenses. Prices are generally negotiated; consequently, there are no published price quotes though Bear River reports its average sales price per ton in the annual report of its parent company, US Antimony. In 2016, Bear River's average sales price for clinoptilolite products was reported as $210/t ($191/st) up, about 9 percent from 2015.

Industry news

Significant producers with their locations and their most important products are noted below.

St. Cloud Mining Co., Inc. (SCM) with operations, mines and deposits in Winston, NM, Ash Meadows, NV and CA, Bowie, AZ and Rome, OR is the largest producer of natural zeolite products in North America. The company sells most of its products under private labeling agreements with brokers, distributors and manufacturers. SCM sells specialty clinoptilolite products for concentrated animal feeding operations (CAFO) that include feed amendments and odor control products, in addition to turf and soil amendments. Water treatment and waste remediation applications are growing. St. Cloud continues to work with partners on new water treatment products and systems. Gas separation and sorption products sales are growing, as well. An expansion of the processing facilities at the Winston, NM site completed in 2016 to process a wider range of products, increase production and packaging flexibility, improve productivity and reduce fixed costs is now fully online. Presently, St. Cloud mines more than half of the zeolite produced in the United States. In early 2016, St. Cloud closed its Ash Meadows facility and consolidated production at the Winston operation. The Ash Meadows plant was sold to KMI, but the Ash Meadows mine remains in full production.

Zeotech in Tilden, TX is a privately held corporation with offices in Texas and New Mexico. Zeotech has a corporate emphasis on producing new applications through research and development. Zeotech was also the first company in the United States to build a plant exclusively for mining, processing and packaging of natural zeolite products. Zeotech markets clinoptilolite filtration media for swimming pools and spas and has developed a new patented surfactant modified product for this application. Zeobrite Xtreme is already in the marketplace for filtration in pool and spa distribution and is also certified NSF 61 for potable water systems. The company also sells adsorbents, modified zeolites for industrial and municipal water treatment and for solid waste and sludge decontamination. Zeotech's main customers are animal feed supplements for mycotoxin binding and color granules for cat litter additives.

Bear River Zeolite a subsidiary of the public company U.S. Antimony Corp. in Preston, ID is the only company that publishes its annual production and financial results. The company has had occasional sales of a clinoptilolite based radioactive waste barrier product for the containment of high level nuclear waste in addition to filtration media, coated clinoptilolite fertilizers and pre-emergent seed products. Bear River reported the following in its annual report for 2015: "During 2016, BRZ sold 11.8 kt (13,100 st) compared to 14.4 kt (15,900 st) in 2015, down 2.5 kt (2,760 st) or 17.3 percent. During 2016, the sales dropped as a result of the drop in oil prices and a sluggish economy."

Teague Mineral Products in Adrian, OR continues to be the largest supplier of clinoptilolite soil conditioners and amendments in Idaho, Oregon and Washington. TMP owns large deposits of clinoptilolite zeolite near the Sheaville and Castle Creek area of Idaho. In the early 1980s, one of the early innovators in the industry, Glenn Teague, added zeolites products to its existing sodium bentonite production. The company started its zeolite business grinding clinoptilolite from the Chrisman Hill deposit for the feed additive industry. After 35 years in the zeolite industry the company sells its zeolite for animal feed additives, hazardous waste cleanup testing (West Valley Nuclear and Atomic Energy of Canada), soil amendments, seed coater, air filtration and odor control.

As are many mineral producers in Oregon, Teague Mineral Products is following a proposal to create a new national monument called the Owyhee Canyonlands National Monument. Its zeolite deposits, as well as St. Cloud's mordenite deposit near Rome, OR would be included. In Malheur County, where Teague Minerals is located, and in adjoining counties the fight continues to stop a possible monument designation and Citizens in Opposition to the Owyhee Canyonlands National Monument has been formed.

UOP LLC, a subsidiary of Honeywell, is the world's largest producer of molecular sieves and operates the EZ Chabazite Mine at Bowie, AZ. The company increased production to supply the rapidly growing market for chabazite molecular sieve products used in pressure swing adsorbent (PSA) plants that purify natural gas. Sales recovered in 2014 and appear to remain strong in 2016, but may have slowed in 2017. The company also supplies some nuclear waste treatment products in partnership with Toshiba at the Fukushima facility.

KMI Zeolite produces clinoptilolite from a deposit near Death Valley National Park, CA. Its processing plant is currently at Sandy Valley, NV. However, the company in the process of relocating its processing to the Ash Meadows facility purchased from St. Cloud in Amargosa Valley, NV. The relocation of the processing operation will not disrupt production, but will allow the company to be closer to its deposit as well as make some equipment upgrades to the existing plant in an effort to triple its overall production to keep expanding with sales. KMI Zeolite focuses mainly on the areas of synthetic turf products, odor elimination, water filtration, soil amendments, animal feed additives and industrial absorbents.

Steelhead Resources in Spokane, WA is a domestic zeolite producer and international provider of natural zeolites including several clinoptilolites, ferrierite, phillipsite and mordenite. Steelhead has worked with a variety of industries to help them identify the appropriate zeolite for each application and then sourced, mined and produced the zeolite to meet its customers' needs and specifications. Steelhead Specialty Minerals is the owner of several deposits and has strong relationships with other zeolite sources in the United States, Steelehead Resources' stated business strategy is that it will find the best zeolite for their customer's business. Steelhead sells clinoptilolite products from deposits in Oregon, California and New Mexico for industrial, agricultural, aquaculture, waste water treatment, odor control and nuclear applications.

Owyhee Mining Co. LLC purchased the private ground containing blocked out reserves of mordenite from the chief geologist for Anaconda Mining Co., which operated there in the early 1980s and is proposing to mine mordenite. The company had its original conditional-use permit issued in 2010 for mining zeolite only. In 2015, an amendment was requested to clarify that the company could mine other minerals as well. The zeolite would be hauled to a rail head in Idaho or Nevada for shipment or directly to customers. OMC received its mining permit from the Oregon Department of Geology and Mineral Industries.

Canadian Zeolite Corp has two deposits one is the Sun Group which is a zeolite deposit held since 2004 and which has drilling to indicate a potentially large resource near transportation infrastructure. The deposit is being held for future development. The company also has the Bromley Creek zeolite deposit about 9 km (5.5 miles) away from Princeton, B.C. Canada with a small drilled out reserve. The company has an agreement with Absorbent Minerals, Ltd to operate, transport, process and package bulk and processed zeolite for its customers both nationally and internationally.

Ashburton Ventures Inc. announced the signing of an agreement to acquire a 100 percent interest in the Z-1 Zeolite Quarry/Mine located about 3 km (1.8 miles) northeast of Cache Creek, BC. from ZMM Canada Minerals Corp. (ZZM), All mining and environmental permits are in place. The Z-1 deposit is located on a main east/west transportation corridor (Trans Canada Highway and CN and CP rail). ZMM was able to purchase the quarry from the previous owner which was disposing the majority of its Canadian assets in 2014.

Uses and applications

Worldwide, most natural zeolite mineral products are used in agricultural soil amendments, odor control, filtration applications and pozzolans that do not require ultra high purity natural or synthetic zeolites. In general, however, most commercial deposits are at minimum 70 to 80 percent zeolite minerals.The exception is an Italian chabazite that at about 50 percent pure, is successfully used in a number of markets in compact septic systems at about 4 kt (4,400 st) annually, as well as other specialty applications. On the other end of the purity range is the chabazite from the Bowie, AZ deposit which is processed into beads and extrudates and then used in specialty sorption applications.Its properties, primarily resistance to harsh chemical environments and a cyclical adsorption rate that exceeds those of the competitive synthetic zeolite products, create a performance advantage. The largest application for chabazite is in PSA plants that treat natural gas from wells and landfills. This market has and will continue to expand over the long term as the worldwide production of natural gas increases.

Trends and outlook

Natural zeolite production should continue to grow at a rate between 3 and 4 percent a year. The markets that will grow most rapidly are:

Animal feeds. A substantial portion of clinoptilolite sold worldwide is used in animal feeds, primarily for cattle. Beef prices in the United States continue at record high prices and it finally appears that the herd is beginning to be rebuilt. It will, however, take a while for this to occur. Feed lots and other large concentrations of animals are point sources of a number of effluents, odors and waste runoffs. There will be increasing regulatory pressure to mitigate the impact of these facilities. Products for swine and poultry are available but have not yet taken off.

Cement, pozzolans and concrete additives. Zeolite pozzolans added to cement improve its physical properties and reduce both the amount of limestone used and carbon dioxide emitted. If the U.S. Environmental Protection Agency designates fly ash from coal-fired power plants as a hazardous waste, it may not be available for use as a pozzolan. In general, the availability of fly ash is decreasing as coal fired plants go offline. A number of companies are looking at volcanic ash and zeolite deposits as some of the only cost effective substitutes available. The major uses of natural zeolites outside the United States are in construction materials and pozzolans. There is also a significant interest in treating fly ash storage areas, which can contain metals and other deleterious contaminants.

Water treatment. Zeolites are used in the filtration pretreatment of reverse osmosis systems for potable water. Zeolite consumption will increase as wastewater recycling and conservation are mandated in the rapidly expanding urban areas of the desert southwest. Testing on mine waters in West Virginia showed that the clinoptilolite from the Winston, NM operation was effective in remediating acid mine drainage as well as reducing aluminum and manganese to acceptable levels both pre and post treatment. Manganese and aluminum have both been compliance issues with mine water discharge at Appalachian coal mining operations in the east, as well as metal mining operations throughout North America. Additionally, ammonia has become a regulatory issue once again in many mining and industrial applications. Large scale water treatment projects using zeolites to remove uranium from groundwater at treatment rates of as much as 4.5 m/min^3 (1,200 gpm) began operations in 2015. Finally, the lead contamination of municipal water in Flint, MI brought national attention to significant issues in the water quality in the United States. Though zeolites were not a solution to water issues at Flint, there are applications for the filtration and treatment of municipal water supplies from both surface and well waters.

Synthetic turf. A growing market for zeolites is the use of the zeolites to control odor in sports turfs and kennels. In addition, the application of zeolites can help control and disperse the heat buildup in sports turfs by absorbing water and then allowing the heat buildup to drive the moisture back off, creating adsorption cooling and acting as a heat sink for the radiant energy as the sun shines on the field.

Odor and pollution control. Suburban residential sprawl into areas that were previously agricultural lands are increasing the use of zeolites for CAFO products used to control the odor from feedlots, dairies and other odor-causing agricultural operations. This is a strong area for future growth.

Nuclear applications

Chabazite and clinoptilolite-based ion exchange products are used to remove radioactive isotopes in nuclear reactor effluents. Clinoptilolite, because of its lower cost, has been used in the construction of extensive impermeable waste barriers to prevent the incursion of radioactive contamination into ground and surface water. Water Remediation Technology, LLC uses a modified clinoptilolite which is NSF 61 certified to remove radium, uranium and other contaminants from municipal water treatment systems and is looking at the increasing problem of trace radioactive contaminants in frac and waste water from the production of natural gas and oil. WRT has more than 100 of these systems installed throughout the United States. One of the more interesting events that began in 2015 and was completed in 2016 was the sale of Kurion, a primary user of natural zeolites at the Fukushima cleanup, to French based Veolia, which is one of the largest water treatment companies in the world. The purchase price was US$350 million. ■

ZIRCONIUM

by George M. Bedinger, National Minerals Information Center, U.S. Geological Survey

Zirconium is the 20th most abundant element in the Earth's crust and occurs in a variety of rock types and geologic environments but most often in the form of zircon ($ZrSiO_4$). Zircon is most often recovered as a coproduct of the mining and processing of placer deposits for heavy mineral sands including the titanium minerals ilmenite and rutile. Placer deposits are formed by the weathering and erosion of rock containing zircon and other heavy minerals and their subsequent concentration in sedimentary systems, particularly in coastal environments.

In 2016, the dominant end use market for zircon was the ceramics industry, which accounted for about 50 percent of the total zircon market. Other markets, in decreasing order, were zirconia [zirconium dioxide (ZrO_2)] and other zirconium chemicals, refractory and foundry applications, and other uses. Zirconia is used in ceramics formulation owing to its high light refractivity, good thermal stability, high melting point, high tensile strength and low thermal conductivity and in glazes for pottery and other ceramic products as an opacifier and pigment. Zirconia and zirconium chemicals can be used for a variety of other uses. Yttria-stabilized zirconia (YSZ) is used in the manufacture of oxygen sensors that control combustion in automobile engines and furnaces and in the manufacture of diverse products including cubic zirconia, fiber optic connectors, refractory coatings and structural ceramics. Zirconium metal is used in corrosive environments and various specialty alloys, and because of its low thermal neutron absorption cross section, hafnium-free zirconium metal is used as cladding for nuclear fuel rod tubes. In refractory and foundry uses, zircon is used for facings on foundry molds where it increases resistance to metal penetration and gives a uniform finish to specialty metal castings. Milled or ground zircon is used in refractory paints for coating the surfaces of molds, and refractory bricks containing zircon are used in furnaces and hearths for containing molten metals.

Table 1

World: Zircon output by country (kt).

	2013	2014	2015	2016[e]
United States[1]	W	W	280	W
Australia	388	798	567	550
China	150	150	140	140
India	40	40	40	40
Indonesia	120	110	110	110
Mozambique	31	51	52	55
Senegal	-	9	45	50
South Africa	224	360	380	400
Other countries	113	101	105	110
Total rounded [2,3]	**1,070**	**1,620**	**1,520**	**1,460**

Source: U.S. Geological Survey
[e] Estimated production.
[1] Data withheld to avoid disclosing company proprietary data
[2] Rounded to one significant digit to avoid disclosing company proprietary data.
[3] Total excludes U.S. production except for 2015.

Production

Global production of zircon concentrates was estimated to be 1.46 Mt (1.6 million st) in 2016, a 4 percent decrease from that of 2015. The leading producing countries, Australia and South Africa, produced 38 percent and 27 percent of global production, respectively (Table 1).

Foreign trade

In 2016, the United States was more than 50 percent import reliant for zircon concentrates, and imported 38.4 kt (42,300 st). The leading import sources were South Africa, Australia and Senegal. China, the leading global consumer of zircon concentrates, imported 1.05 Mt (1.15 million st) in 2016, virtually unchanged from those in 2015.

Prices

Zircon prices for bulk zircon to China, bagged zircon from Australia and U.S. imports continued a slightly downward trend throughout 2016 (Fig. 1). Iluka Resources Ltd. of Australia, the largest global producer of zircon, lowered its weighted average price of zircon in 2016 by 22 percent, to $773/t ($701/st) owing to competitor price reductions and a change in its overall product mix to a less expensive grade of zircon concentrate.

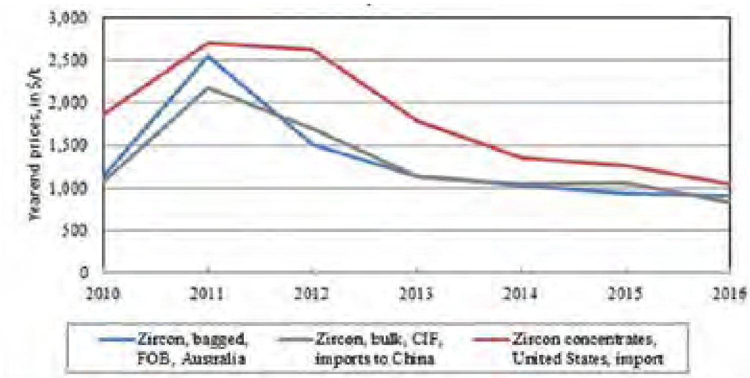
Industry news

Tronox Ltd. (Stamford, CT) began production at its Fairbreeze Mine in South Africa in late 2015, and officially opened the mine in April 2016. The Fairbreeze Mine had a mine life based on reserves of more than 12 years at 55 kt/a (61,000 st) of zircon. Fairbreeze was developed as a replacement for the Hillendale Mine, which closed in early 2014.

In February 2017, Tronox announced an agreement to acquire The National Titanium Dioxide

Figure 1

Average prices, yearend. CIF-Cost, insurance and freight; Free on Board. Source: U.S. Census Bureau, TZ Minerals International Pty Ltd.



Company Ltd. (Cristal) (Jeddah, Saudi Arabia), which included eight titanium dioxide plants and six mineral sands mines with associated processing plants. In order to fund the acquisition, Tronox was planning to sell noncore assets and use cash on hand. If the agreement was approved by shareholders and met regulatory approval, the combined company's mineral sands operations would rival Iluka as the leading global producer of zircon concentrates. The acquisition was expected to be completed by the first quarter of 2018.

Outlook

TZ Minerals International Pty. Ltd., an independent consulting company that focuses on zircon and titanium minerals and end–use markets, was expecting little increase in demand for zircon in 2017 owing to producer supplies remaining high, especially for the premium zircon market. Conversely, Iluka was expecting demand growth in 2017 and 2018 owing to better balance of zircon inventories held by end users and sales of first quarter inventories secured at higher prices. ■