

2013 Minerals Yearbook

DIAMOND, INDUSTRIAL [ADVANCE RELEASE]

DIAMOND, INDUSTRIAL

By Donald W. Olson

Domestic survey data and tables were prepared by Connie Lopez, statistical assistant, and the author. The world production table was prepared by Glenn J. Wallace, international data coordinator.

In 2013, U.S. synthetic diamond production was estimated to be 108 million carats with an estimated value of \$73.2 million. U.S. imports of natural and synthetic industrial diamond bort, dust, grit, powder, and stone totaled 728 million carats valued at \$79.8 million, and exports totaled 134 million carats valued at \$70.1 million. The estimated U.S. apparent consumption of industrial diamond bort, dust, grit, powder, and stone totaled 740 million carats with an estimated value of \$102 million. Total industrial diamond output worldwide was estimated by the U.S. Geological Survey (USGS) to be 4.45 billion carats valued between \$1.65 and \$2.50 billion. This was the combination of more than 59.9 million carats of natural industrial diamond and about 4.39 billion carats of synthetic industrial diamond (table 1).

Diamond is best known as a gemstone, but some of its unique properties make it ideal for many industrial and research applications. Current information on gem-grade diamond can be found in the USGS Minerals Yearbook, volume I, Metals and Minerals, chapter on gemstones. Diamond that does not meet gem-quality standards for clarity, color, shape, or size is used as industrial-grade diamond. Total production and consumption quantities and values in table 1 are estimated based on past and current reported data. Trade data in this report are from the U.S. Census Bureau. All percentages in the report were computed using unrounded data.

Production

The USGS conducts an annual survey of domestic industrial diamond producers and U.S. firms that recover diamond wastes. Although most of these companies responded to the 2013 survey, one of the two companies that are producers of synthetic industrial diamond and one of the three industrial diamond recycling firms did not. Production quantities and values for the nonreporting companies were estimated based on industry production trends, reports from some producers and other industrial diamond industry. The USGS does not conduct surveys of domestic polycrystalline diamond (PCD) producers or domestic chemical vapor deposition (CVD) diamond producers for quantity or value of annual production.

As one of the world's leading producers of synthetic industrial diamond, the United States accounted for an estimated output of 108 million carats valued at more than \$73.2 million in 2013. Only two U.S. companies produced synthetic industrial diamond during the year—Diamond Innovations, Inc. (Worthington, OH) and Mypodiamond, Inc. (Smithfield, PA). Diamond Innovations, Inc. is a wholly owned subsidiary of Sandvik Group.

In 2013, at least eight U.S. companies also manufactured PCD from synthetic diamond grit and powder. These companies were Dennis Tool Co. (Houston, TX), Diamond Innovations, Novatek Inc. (Provo, UT), Precorp Inc. (Provo), Sii MegaDiamond Inc.

(Provo), Tempo Technology Corp. (Somerset, NJ), US Synthetic Corp. (Orem, UT), and Western Diamond Products LLC (Salt Lake City, UT).

During 2013, an estimated 38.4 million carats of used industrial diamond worth about \$19.3 million (table 1) was recycled in the United States. Recycling firms recovered most of this material from used diamond drill bits, diamond tools, and other diamond-containing wastes. Additional diamond was recovered during the year from residues generated in the manufacture of PCD.

The recovery and sale of industrial diamond was the principal business of three U.S. companies in 2013—Industrial Diamond Laboratory, Inc. (Bronx, NY), International Diamond Services Inc. (Houston, TX), and National Research Co. (Fraser, MI). In addition to these companies, other domestic firms may have recovered industrial diamond in smaller secondary operations.

Since the 1950s, when scientists manufactured the first synthetic bits of diamond grit using a high-pressure, high-temperature (HPHT) method, this method of growing diamonds has become relatively commonplace in the world as a technology for synthetic diamonds, so much so that thousands of small plants throughout China were using the HPHT method and producing synthetic diamonds in 2013. Diamonds of 1 carat or more are harder to manufacture because, at that size, it is difficult to consistently produce diamonds of high quality, even in the controlled environment of a laboratory using the HPHT method. After more than 50 years of development, several synthetic diamond companies were able to produce relatively large high-quality industrial diamonds that equaled those produced from mines (Park, 2007).

In the early 2000s, technology was developed for a method for growing single, extremely pure diamond crystals by CVD. The CVD technique transforms carbon into plasma, which is then precipitated onto a substrate as diamond. CVD had been used for more than a decade to cover large surfaces with microscopic diamond crystals, but in developing this process, synthetic diamond producers discovered the temperature, gas composition, and pressure combination that resulted in the growth of a single diamond crystal and were able to produce synthetic stones that ranged from 1 to 2 carats.

During 2013, Scio Diamond Technology Corp. (Greenville, SC) used CVD technology to produce synthetic single crystal diamond stones that ranged from 1 to 2 carats for gemstone and industrial use. Scio Diamond Technology Corp. and Gemesis Diamond Co. prefer to call their diamonds "cultured" rather than synthetic, referring to the fact that the diamonds are grown much like a cultured pearl is grown. Scio Diamond reported that for the fiscal year ending March 31, 2014, they had manufactured more than 23,000 carats of rough diamond. This production was

a 49% increase over the previous fiscal year's production (Scio Diamond Technology Corp., 2014).

No commercial diamond mines operated in the United States during 2013. The last commercially operated diamond mine in the United States closed in 2002 and was fully reclaimed.

Consumption

Diamond is the hardest known material and has the highest thermal conductivity of any material at room temperature. Diamond is more than twice as hard as its nearest competitors, cubic boron nitride and silicon nitride. Because of its hardness, diamond has been used for centuries as an abrasive in cutting, drilling, grinding, and polishing. Industrial-grade diamond continues to be used as an abrasive for many applications. Even though it has a higher unit cost than alternative abrasive materials, diamond has proven to be more cost-effective in many industrial processes because it cuts faster and lasts longer than alternatives. Diamond also has chemical, electrical, optical, and thermal characteristics that make it the best material available to industry for wear- and corrosion-resistant coatings, special lenses, heat sinks in electrical circuits, wire drawing, computing, and other advanced technologies.

Both natural and synthetic diamonds have industrial uses. Synthetic industrial diamond is superior to its natural diamond counterpart because its properties can be tailored to specific applications, and it can be produced in large quantities.

The United States remained the world's leading market for industrial diamond in 2013. Based on production estimates and trade data, U.S. apparent consumption of industrial diamond during the year increased by 28% to an estimated 740 million carats valued at \$102 million compared with 580 million carats valued at \$92.0 million in 2012 (table 1). This increase was due to industrial sectors that consume industrial diamond continuing to recover from the economic recession and a decrease in the average cost of natural industrial diamond imports. Apparent consumption was the combination of 19.7 million carats of natural industrial diamond valued at \$8.91 million and 720 million carats of synthetic industrial diamond valued at \$93.3 million. By type, apparent consumption was the combination of 675 million carats of diamond bort, dust, grit, and powder valued at \$33.2 million and 64.8 million carats of diamond stone valued at \$68.9 million.

The major consuming industrial sectors of industrial diamond cutting and drilling tools and abrasives in the United States during 2013 were construction, machinery manufacturing, mining services (exploration drilling for minerals, natural gas, and oil), stone cutting/polishing, and transportation systems (infrastructure and vehicles). Within these sectors, highway building/repair and stone cutting, combined, accounted for the majority of demand for industrial diamond. Research and hightechnology uses included close-tolerance machining of ceramic parts for the aerospace industry, heat sinks in electronic circuits, lenses for laser radiation equipment, polishing of silicon wafers and disk drives, and other applications in the computer industry.

Diamond tools have numerous industrial functions. Diamond drilling bits and reaming shells are used principally for extraction of minerals, natural gas, and oil. Other applications of diamond bits and reaming shells include foundation testing, inspecting concrete, and masonry drilling. The primary uses of point diamond tools are for dressing and truing grinding wheels and for boring, cutting, finishing, and machining applications. Beveling glass for automobile windows is another application. Cutting dimension stone and cutting/grooving concrete in highway reconditioning are the main uses of diamond saws; other applications include cutting composites and forming refractory shapes for furnace linings. Very fine diamond saws are used to slice brittle metals and crystals into thin wafers for electronic and electrical devices. Diamond wire dies are essential for high-speed drawing of fine wire, especially from hard, high-strength metals and alloys. The primary uses of diamond grinding wheels include edging plate glass, grinding dies, grinding parts for optical instruments, and sharpening and shaping carbide machine tool tips.

Two types of natural diamond are used by industry—diamond stone (generally larger than 60 mesh, or 250 micrometers) and diamond bort (smaller, fragmented material). Diamond stone is used mainly in drill bits and reaming shells used by mining companies; it also is incorporated in single- or multiple-point diamond tools, diamond saws, diamond wheels, and diamond wire dies. Diamond bort is used for drill bits and as a loose grain abrasive for polishing. Other tools that incorporate natural diamond include bearings, engraving points, glass cutters, and surgical instruments.

Synthetic diamond grit and powder are used in diamond grinding wheels, saws, impregnated bits and tools, and as a loose abrasive for polishing. Diamond grinding wheels can be as large as 1 meter in diameter.

Loose powders made with synthetic diamond for polishing are used primarily to finish cutting tools, drill bits, gemstones, jewel bearings, optical surfaces, reaming shells, silicon wafers, and wire-drawing dies for computer chips. Hundreds of other products made from ceramics, glass, metals, and plastics also are finished with diamond powders.

Consumption quantity and value data are not available for PCD or for CVD diamond. Two types of PCDs used by industry are polycrystalline diamond compacts (PDCs) and polycrystalline diamond shapes (PDSs). The use of PDCs and PDSs continues to increase for many of the applications cited above, including some of those that employ natural diamond. PDCs and PDSs are used in the manufacture of single- and multiple-point tools, and PDCs are used in a majority of the diamond wire-drawing dies.

Since its introduction in the mid-1980s, CVD diamond has seen strong growth and has been increasingly accepted by multiple industries as an enhanced material of choice owing to its properties of exceptional strength, durability, stiffness, high thermal conductivity, and electrical isolation. The global market value of industrial diamond and diamond-like films and coatings was estimated to have been more than \$905 million in 2010 and was expected to increase to more than \$1.7 billion by 2015.

Early applications for CVD diamond focused largely around thin- and thick-film PCD for cutting tools and dressing applications because of the mechanical properties of diamond. Newer applications that take advantage of CVD diamond's mechanical properties include wear parts, such as watch gears and chemical mechanical polishing pad conditioners. Diamond has tremendous potential for electronics applications because it significantly improves upon current strategies for thermal management while remaining highly cost competitive with other approaches. CVD diamond is used in microelectronic components, such as high-speed processors, medical devices, wide bandgap radio frequency (RF) devices, power conversion devices, and opto-electronic devices (light-emitting diodes, laser diodes) that generate exceptionally high heat densities requiring innovative approaches to thermal management. Diamond coatings are increasingly being used in these applications because the thermal conductivity of diamond is 10 times that of silicon. In the manufacture of semiconductors, waferscale diamond offers enhanced mechanical properties, such as significantly higher stiffness, strength, hardness, thermal conductivity, and chemical inertness, compared with silicon and most other commonly used thin-film materials. Microelectro-mechanical systems (MEMS), such as radio frequency MEMS resonators, have design needs that can be met by the use of diamond as a base material because of its very high resistance to being deformed elastically when a force is applied and because of its durability in harsh environments. Researchers are investigating the use of boron-doped diamond (BDD) electrodes for water treatment owing to 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 (Zimmer, 2011).

Historically, diamond has been perceived as an expensive material. Advances in CVD diamond manufacturing, such as the development of microwave carbon plasma technology and the development of higher throughput hot filament (HF) CVD diamond reactors, have significantly reduced diamond costs. This led many industries to revisit development activities and actively pursue the use of CVD diamond for an increasing number of applications (Zimmer, 2011).

In addition to the existing opportunities for their cultured diamond gemstones, Scio Diamond was developing the use of single-crystal CVD diamond materials in high-voltage power switches, lasers, quantum communications and computing, and water treatment and purification. Scio Diamond reported that these projects could translate into market opportunities exceeding \$1 billion and high-volume technology applications in the next 5 years (Scio Diamond Technology Corp., 2012).

Prices

Diamond prices were at record-high levels in 2011; they slowly decreased during 2012 and 2013. Industrial diamond prices began to drop in September 2011, and prices of rough and industrial diamonds continued decreasing throughout 2012 and 2013. These price decreases were the result of a combination of factors, including declining marginal demand from the emerging consumer markets of China and India; the impact of the relatively weak U.S. economy and the financial crisis in the European Union; the devaluation of the Indian rupee; and the pricing policies of the main producers, De Beers' subsidiary Diamond Trading Co. (DTC) and OJSC ALROSA, refusing to drop prices despite their clients' struggle to retain profitability. By mid-2012, the clients began rejecting their rough diamond allocations, and DTC and ALROSA were forced to reduce prices (Botswana Diamonds P.L.C., 2013). Factors that affect the prices of natural gemstone diamond affect prices of natural industrial diamond as well (Roffman, 2011).

Natural and synthetic industrial diamonds differ significantly in price. Natural industrial diamond normally had a more limited range of values, from about \$0.49 per carat for bort size material to about \$2.50 to \$10 per carat for most stones, with some larger stones having sold 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 for grinding and polishing ranged from as low as \$0.26 per carat to \$2.50 per carat. Strong and blocky material for sawing and drilling sold for \$2.50 to \$4.00 per carat. Large, synthetic crystals with excellent structure for specific applications sold for several hundred dollars per carat. During 2013, U.S. imports of all types of industrial diamond had an average value of \$0.11 per carat. These imports were a combination of diamond bort, dust, grit, and powder (natural and synthetic) that had an average value of \$0.11 per carat and diamond stone (natural and synthetic) that had an average value of \$15.46 per carat. These average unit values for imported diamond bort, dust, grit, and powder (natural and synthetic) were lower than the average reported prices for the same size fractions of domestically produced diamond listed above.

Foreign Trade

The United States continued to lead the world in industrial diamond trade in 2013; imports were received from 41 countries and exports and reexports were sent to 43 countries (tables 2–5). Although the United States has been a major producer of synthetic diamond for decades, expanding domestic markets have become more reliant on foreign sources of industrial diamond in recent years. U.S. markets for natural industrial diamond have always been dependent on imports and secondary recovery operations because natural diamond has not been produced domestically.

During 2013, U.S. imports of industrial-quality diamond stones (natural and synthetic) decreased by 17% from those of 2012 to 1.94 million carats valued at \$30.0 million (table 2). Imports of diamond dust, grit, and powder (natural and synthetic) increased by 22% from those of 2012 to 728 million carats valued at \$79.8 million (table 3).

Reexports accounted for a significant portion of total exports; therefore, exports and reexports are listed separately in tables 4 and 5 so that U.S. trade and consumption can be calculated more accurately. During 2013, the United States did not export industrial diamond stones, unchanged from 2012. U.S. reexports of industrial diamond stone decreased by 22% from those of 2012 to 15.5 million carats valued at \$30.0 million and an average value of \$1.94 per carat (table 4). U.S. exports of industrial diamond dust, grit, and powder (natural and synthetic) decreased by 14% from those of 2012 to 134 million carats valued at \$70.1 million and an average value of \$0.52 per carat. Reexports of industrial diamond dust, grit, and powder (natural and synthetic) decreased by 25% from those of 2012 to 21.9 million carats valued at \$9.98 million and an average value

of \$0.46 per carat (table 5). Trade quantity and value data are not available for PCD or for CVD diamond.

World Industry Structure

Global natural diamond production increased slightly during 2013 to 130 million carats from 128 million carats in 2012. The world's leading rough diamond producers, in decreasing order of quantity produced, were as follows: Russia, producing 37.9 million carats or 29% of total world production; Botswana, with 23.2 million carats (18%); Congo (Kinshasa), with 15.7 million carats (12%); Australia, with 11.7 million carats (9%); Canada, with 10.6 million carats (8%); Zimbabwe, with 10.4 million carats (8%); Angola, with 9.36 million carats (7%); South Africa, with 8.14 million carats (6%); and other countries, with 3.52 million carats (3%) (table 6). Of the 130 million carats total natural diamond production, 70.6 million carats (54% of total diamond production) was gemstone diamond and 59.9 million carats (46% of total diamond production) was industrial diamond. Total combined natural and synthetic industrial diamond output worldwide was estimated by the USGS to be about 4.45 billion carats (table 1).

During 2013, De Beers and ALROSA continued to be the two leading diamond-producing groups by quantity and value. De Beers' production was 21% of total global quantity and 33% of total global value; ALROSA's production was 25% of total global quantity and 26% of total global value. The third-ranked company was Rio Tinto, which produced 11% of total global production quantity and approximately 5% of global production value. Another leading producer was Angola's Catoca Mine, generating approximately 5% of total global production quantity and value. The companies that operated the alluvial fields of Chiadzwa in Zimbabwe contributed an estimated 8% of total global production quantity and 4% of value (De Beers Group Inc., 2014, p. 42).

In 2002, the international rough-diamond certification system, the Kimberley Process Certification Scheme (KPCS), was agreed upon by United Nations (UN) member nations, the diamond industry, and involved nongovernmental organizations to prevent the shipment and sale of conflict diamonds. Conflict diamonds are diamonds that originate from areas controlled by forces or factions opposed to legitimate and internationally recognized Governments, and are used to fund military action in opposition to those Governments or in contravention of the objectives of the UN Security Council. The KPCS monitors rough-diamond trade in both gemstone and industrial diamond. The KPCS includes the following key elements: the use of forgery-resistant certificates and tamper-proof containers for shipments of rough diamonds; internal controls and procedures that provide credible assurance that conflict diamonds do not enter the legitimate diamond market; a certification process for all exports of rough diamonds; the gathering, organizing, and sharing of import and export data on rough diamonds with other participants of relevant production; credible monitoring and oversight of the international certification scheme for rough diamonds; effective enforcement of the provisions of the certification scheme through dissuasive and proportional penalties for violations; self regulation by the diamond industry that fulfills minimum requirements; and sharing information

with all other participants on relevant rules, procedures, and legislation as well as examples of national certificates used to accompany shipments of rough diamonds. South Africa assumed the chair of KPCS for the country's second term from January 1 through December 31, 2013. As of August 2, 2013, the 54 participants represented 81 nations (including the 28 member nations of the European Community) plus the rough-diamondtrading entity of Taipei (Taiwan). During 2013, the Central African Republic was under a temporary suspension of exports and imports of rough diamonds, Côte d'Ivoire continued to be under UN sanctions and was not trading in rough diamonds, and Venezuela voluntarily suspended exports and imports of rough diamonds until further notice. The participating nations in the KPCS account for approximately 99.8% of the global production and trade of rough diamonds (Kimberley Process, undated).

In 2013, natural industrial diamond was produced in 12 countries (table 6). Natural industrial diamond production worldwide was estimated to be about 59.9 million carats, a slight decrease compared with 61.2 million carats in 2012. Russia was the leading natural industrial diamond producing country with 16.7 million carats or 28% of total world production; followed by Congo (Kinshasa), with 12.5 million carats (21%); Australia, with 11.5 million carats (19%); Zimbabwe, with 9.37 million carats (16%); and Botswana, with 6.96 million carats (12%) in descending order of quantity. These five countries produced almost 95% of the world's natural industrial diamond (table 6). Synthetic industrial diamond production worldwide was estimated to be more than 4.39 billion carats, a slight increase compared with that of 2012. China was the leading producing country, followed by the United States, Russia, Ireland, and South Africa, in descending order of quantity. These five countries produced about 98% of the world's synthetic industrial diamond.

In 2013, 97% of the total global combined natural and synthetic industrial diamond output was produced in China, Ireland, Russia, South Africa, and the United States. Synthetic diamond accounted for more than 99% of global diamond production and consumption.

Worldwide diamond exploration spending decreased by 6% in 2013 with 47 companies allocating \$489 million, compared with 65 companies allocating \$520 million during 2012. The diamond share of overall worldwide mineral exploration spending was 3.4%. Africa was the leading diamond exploration location (SNL Metals Economics Group, 2013, p. 83).

In 2013, worldwide average diamond values decreased by 4% to \$95.00 per carat from the 2012 average value of \$98.81 per carat. The major reasons for this decrease was lower demand in China and India in 2013 compared with 2012. During the first half of the year, price decreases were moderated by steady demand in the United States (SNL Metals Economics Group, 2014, p. 2).

Four new diamond projects started production in 2013: the Grib Pipe Mine in Russia and three other new, much smaller mines—the Merlin Mine in Australia, the Mobilong Diamond Mine in Cameroon, and the Saxendrift Mine in South Africa (SNL Metals Economics Group, 2014, p. 8).

World Review

Australia.—Diamond production in Australia was 11.7 million carats during 2013, a 27.8% increase compared with that of 2012, accounting for 9.0% of total global production.

The Merlin Mine, in the Northern Territory, was a redevelopment project. The mine, originally owned by Rio Tinto Group, closed after exhausting its reserves in 2003. Merlin Diamonds Ltd. acquired the mine in 2004 and subsequently determined that the deposit contained 2.9 million carats in proven reserves and an additional 4.6 million carats in inferred resources. Merlin Diamonds expected to produce 250,000 carats per year (SNL Metals Economics Group, 2014, p. 8).

In April 2013, Rio Tinto announced the official opening of the new Argyle underground diamond mine, in the region of Western Australia east of Kimberley. The Argyle Mine had been operating as an open pit mine since 1983 and had produced more than 800 million carats of rough diamonds. It has been one of the world's leading suppliers of diamonds and the world's largest supplier of natural colored diamonds. Rio Tinto projected that the move from open pit mining to an underground operation would extend the life of the Argyle Mine until at least 2020. The \$2.2 billion underground mine used the most up-todate block caving technology and was the first of its kind in Western Australia. Rio Tinto estimated that the average annual production over the life of the underground mine was likely to be 20 million carats per year (Rio Tinto Group, 2013).

Canada.—Diamond production in Canada was 10.6 million carats during 2013, a slight increase compared with that of 2012, accounting for 8.1% of the world's combined natural gemstone and industrial diamond output. Diamond exploration continued in Canada, with several commercial diamond projects and additional discoveries in Alberta, British Columbia, the Northwest Territories, the Nunavut Territory, Ontario, and Quebec.

The Ekati Diamond Mine, Canada's first operating commercial diamond mine, completed its 15th full year of production in 2013 under new ownership. On April 10, 2013, Dominion Diamond Corp., formerly Harry Winston Diamond Corp., finalized its acquisition of an 80% controlling interest in the Ekati Diamond Mine and its diamond sorting and sales facilities from BHP Billiton Canada Inc. for \$553 million (Dominion Diamond Corp., 2014b). Ekati produced 1.17 million carats of diamond from 2.44 million metric tons of ore during the period of April 10, 2013, through December 31, 2013. About 20% of the Ekati diamond production was industrial-grade material (Dominion Diamond Corp., 2014a).

Cameroon.—Diamond production in Cameroon was about 3,000 carats during 2013. In mid-2013, C and K Mining, Inc. began production at the Mobilong Diamond Mine. C and K Mining, which was a joint venture between the Governments of Cameroon and the Republic of Korea, intended to increase production from an initial 50,000 carats per year to 800,000 carats per year (SNL Metals Economics Group, 2014, p. 8).

Russia.—Diamond production in Russia was 37.9 million carats during 2013, an 8.5% increase compared with that of 2012, accounting for 29.0% of total global production. In October 2013, the Government of Russia privatized 16% of its stake in ALROSA, by way of an initial public offering, for \$1.3 billion (De Beers Group Inc., 2014, p. 44).

OAO LUKOIL brought its wholly owned Grib Pipe Mine in the Arkhangelsk Region of Russia into production at the end of 2013. The mine started production as an open pit that was expected to produce about 58 million carats during its projected 16-year mine life and then transition to an underground mine to produce an additional 40 million carats. Production was expected to be 3 to 4 million carats per year. Initial development of the open pit mine was projected to cost \$850 million; no capital cost estimate for the underground mine was available. Grib Pipe has unclassified reserves containing 98.5 million carats (SNL Metals Economics Group, 2014, p. 8).

South Africa.—Diamond production in South Africa was 8.1 million carats during 2013, a 15.1% increase compared with that of 2012, accounting for 6.2% of total global production.

Rockwell Diamonds Inc. began production at the Saxendrift Mine with estimated output of 10,000 carats per year. The Saxendrift is an alluvial mine, 74% owned by Rockwell Diamonds and 26% owned by BEE Group. The mine was adjacent to the Middle Orange River approximately 160 kilometers southwest of Kimberley. The plant was commissioned with a capacity to process 115,000 cubic meters per month and was expected to increase to full capacity of 200,000 cubic meters per month. The alluvial deposit hosted 11.9 million cubic meters grading 0.005 carats per cubic meter (SNL Metals Economics Group, 2014, p. 8).

Outlook

China is expected to remain the world's leading producer of synthetic industrial diamond, with annual production exceeding 4 billion carats. The United States is likely to continue to be one of the world's leading markets for industrial diamond into the next decade and likely will remain a significant producer and exporter of synthetic industrial diamond as well. U.S. industrial diamond production and apparent consumption are expected to continue increasing as manufacturing sectors that use industrial diamond recover from the negative effects of the economic recession that started in mid-2008. U.S. demand for industrial diamond is likely to continue in the construction sector as the United States continues building and repairing the Nation's highway system.

Diamond offers many advantages for precision machining and longer tool life. In fact, even the use of wear-resistant diamond coatings to increase the life of materials that compete with diamond is a rapidly growing application. Increased tool life not only leads to lower costs per unit of output but also means fewer tool changes and longer production runs. In view of the many advantages that come from increased tool life and reports that diamond film surfaces can increase durability, much wider use of diamond as an engineering material is expected.

PCD for abrasive tools and wear parts is likely to continue to replace competing materials in many industrial applications by providing closer tolerances as well as extending tool life. For example, PDCs and PDSs will continue to displace natural diamond stone and tungsten carbide products used in the drilling and tooling industries.

CVD technology can produce extremely pure diamond crystals that have great potential in computer technology in the production of diamond computer chips when their cost becomes competitive. These diamond computer chips will work at a much higher frequency or faster speed and can be placed in higher temperature environments than the silicon chips currently used in computers. Eventually, they may replace silicon chips in computers. CVD diamonds annealed using the low-pressure, high-temperature microwave plasma process may have applications in high-pressure research, optical applications that take advantage of the outstanding transparency of diamond, and in quantum computing to store quantum information in vacancy centers in the diamond's crystal lattice.

CVD diamond is likely to be used to provide a better and more efficient alternative process to existing water purification processes. This technology will use single-crystal diamond electrodes for electrochemical water purification.

Truing and dressing applications will remain a major domestic end use for natural industrial diamond stone. Stones for these applications have not yet been manufactured economically. No shortage of the stone is anticipated, however, because new mines and more producers selling in the rough diamond market will maintain ample supplies. More competition introduced by the additional sources also may temper price increases.

Demand for synthetic diamond bort, dust, grit, and powder is expected to remain greater than for natural diamond material. Constant-dollar prices of synthetic diamond products are likely 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.

References Cited

- Botswana Diamonds P.L.C., 2013, Diamond market report—H2 2012: Dublin, Ireland, Botswana Diamonds P.L.C., January 21, 5 p. (Accessed February 10, 2014, at http://www.botswanadiamonds.co.uk/res/file/diamondmarket-h2-2012.pdf.)
- De Beers Group Inc., 2014, The diamond insight report—2014: London, United Kingdom, De Beers UK Ltd., October 7, 86 p. (Accessed May 5, 2015, at http://insightreport.debeersgroup.com/_downloads/pdfs/de-beers-insight-report-2014.pdf.)
- Dominion Diamond Corp., 2014a, Dominion Diamond Corporation reports Diavik and Ekati Diamond Mine fourth calendar quarter production: Toronto, Ontario, Canada, Dominion Diamond Corp. news release, January 15. (Accessed December 18, 2014, at http://www.ddcorp.ca/investors/newssingle?id=1891240.)
- Dominion Diamond Corp., 2014b, Dominion Diamond Corporation reports fiscal 2014 fourth quarter and year-end results: Toronto, Ontario, Canada, Dominion Diamond Corp. news release, April 2, 72 p. (Accessed

December 18, 2014, via http://www.ddcorp.ca/investors/news-releases?year=2014.)

Kimberley Process, [undated], The Kimberley Process: New York, NY, Kimberley Process. (Accessed December 18, 2014, via http://www.kimberleyprocess.com/.)

Park, Alice, 2007, Diamonds de novo: TIME, v. 169, no. 7, February 12, p. G1. Rio Tinto Group, 2013, Rio Tinto officially opens its Argyle underground mine:

- Melbourne, Victoria, Australia, Rio Tinto Group media release, April 30, 2 p. (Accessed December 17, 2014, at http://www.riotinto.com/documents/ MediaReleases-diamonds/130430_Rio_Tinto_officially_opens_its_Argyle_ underground_mine.pdf.)
- Roffman, Steve, 2011, Natural industrial diamonds—Update 2011: Finer Points, winter, p. 22.
- Scio Diamond Technology Corp., 2012, Scio Diamond Technology releases letter to shareholders: Greenville, SC, Scio Diamond Technology Corp. press release, January 4. (Accessed July 31, 2013, at http://www.sciodiamond.com/ scio-diamond-technology-releases-letter-to-shareholders.html.)
- Scio Diamond Technology Corp., 2014, Scio Diamond Technology Corp., reports 49% increase in diamond production year-over-year for fiscal 2014: Greenville, SC, Scio Diamond Technology Corp. press release, April 29. (Accessed December 17, 2014, at http://www.sec.gov/Archives/edgar/ data/1488934/000110465914031632/a14-11445_1ex99d1.htm.)
- SNL Metals Economics Group, 2013, A worldwide analysis—Exploration budgets by target: SNL Metals Economics Group Corporate Exploration Strategies Report, October, p. 63–122.
- SNL Metals Economics Group, 2014, Diamond pipeline, 2014: SNL Metals Economics Group Strategic Report, v. 27, no. 3B, March, 15 p.
- Zimmer, Jerry, 2011, CVD diamond comes into its own: Finer Points, winter, p. 23.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

- Abrasives. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
- Diamond (Industrial). Ch. in Mineral Commodity Summaries, annual.
- Historical Statistics for Mineral and Material Commodities in the United States. Data Series 140.

Other

De Beers Consolidated Mines Ltd. annual reports, 1998–2001. Diamond, Industrial. Ch. in Mineral Facts and Problems, U.S.

Bureau of Mines Bulletin 675, 1985.

Finer Points, quarterly.

Industrial Diamond Review, quarterly.

World Diamond Industry Directory & Yearbook, 1998–99.

SALIENT NATURAL AND SYNTHETIC INDUSTRIAL DIAMOND STATISTICS¹

(Thousand carats and thousand dollars)

	2009	2010	2011	2012	2013
United States:					
Natural:					
Secondary production:					
Quantity ^e	16,700 ²	16,700	17,300	18,300	19,000
Value ^e	8,150	8,190	8,470	8,920	9,240
Exports:					
Quantity	1,510	2,330	3,710	6,500	4,210
Value	2,280	1,780	1,780 ^r	4,100	2,470
Imports for consumption:					
Quantity	2,840 r	4,750 r	7,320 r	4,190 r	4,910
Value	1,760 ^r	2,570 r	4,070 r	2,040 r	2,130
Synthetic:					
Primary production:					
Quantity ^e	91,000 ²	93,000	98,200	103,000	108,000
Value ^e	65,100	66,400	67,100	70,600	73,200
Secondary production:					
Quantity ^e	17,200 2	17,100	17,700	18,600	19,400
Value ^e	9,080	9,120	9,260	9,750	10,100
Exports:					
Quantity	65,500	110,000	146,000 ^r	149,000 ^r	130,000
Value	31,100	51,000	68,600	73,200	67,600
Imports for consumption:					
Quantity	243,000	591,000	721,000 r	591,000 r	723,000
Value	39,100 r	83,800 r	93,700 ^r	78,000 r	77,600
Apparent consumption, natural and synthetic: ³					
Quantity	304,000 ^r	610,000 ^r	712,000 ^r	580,000 ^r	740,000
Value	89,800 r	117,000 r	112,000 r	92,000 r	102,000
World:					
Production, natural ^e	56,400 ^r	58,400 ^r	55,600 ^r	61,200 ^r	59,900
Production, synthetic ^e	4,370,000	4,380,000	4,380,000	4,390,000 r	4,390,000
Production, natural and synthetic ^e	4,430,000 r	4,430,000 r	4,440,000 r	4,450,000 r	4,450,000

^eEstimated. ^rRevised.

¹Data are rounded to no more than three significant digits.

²Reported figure.

³Domestic primary and secondary production plus imports minus exports.

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND STONES, BY COUNTRY $^{\rm 1}$

	Natura	l industria	l diamond st	Miners' diamond, natural and synthetic ³				
	201	2	2 2013		2012		2013	
Country	Quantity	Value ⁴	Quantity	Value ⁴	Quantity	Value ⁴	Quantity	Value ⁴
Australia	44	976	91	1,260	2	20		
Belgium	175	1,120	12	208	5	28	(5)	35
Botswana	505	21,600	323	14,800				
Congo (Kinshasa)	5	157	7	57			(5)	19
Ghana	2	82	(5)	2				
India	862	933	512	596	22	416	21	121
Namibia	219	1,270	157	1,530			(5)	7
Russia	7	101	16	342				
South Africa	482	8,680	747	9,180	1	36	5	242
Other	3	157	43	336	(5)	128	6	1,280
Total	2,300	35,100	1,910	28,300	30	628	32	1,710

(Thousand carats and thousand dollars)

-- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Includes glazers' and engravers' diamond unset, Harmonized Tariff Schedule of the United States (HTS) codes 7102.21.3000 and 7102.21.4000.

³HTS codes 7102.21.1010 and 7102.21.1020.

⁴Customs value.

⁵Less than ¹/₂ unit.

Source: U.S. Census Bureau.

U.S. IMPORTS FOR CONSUMPTION OF DIAMOND DUST, GRIT, AND POWDER, BY COUNTRY¹

		Nat	ural ²			Syn	thetic ³		
	201	2012		2013		2012		2013	
Country	Quantity	Value ⁴	Quantity	Value ⁴	Quantity	Value ⁴	Quantity	Value ⁴	
Belgium	130 ^r	74 r	84	46	1,100	283	1,200	427	
China	919 ^r	96 r	713	166	445,000 r	33,100 ^r	591,000	40,100	
Germany	34 ^r	27 r	194	115	11	8	194	98	
Hong Kong	r	r	4	4	204	79	775	118	
India	1,470 ^r	896 r	1,640	679	498 r	312 ^r	298	166	
Ireland	474 ^r	345 r	526	313	58,900	24,900	48,700	21,400	
Israel	r	r			143	77	160	58	
Italy	2 ^r	4 r			7	5	4	19	
Japan	r	r			1,290	1,750	885	1,150	
Korea, Republic of	r	r	2	4	26,300	9,350	16,500	5,310	
Mexico	211	37	23	25					
Romania	r	r			25,300 r	2,130 r	34,800	2,030	
Russia	124 ^r	74 ^r	965	244	14,200	2,110 r	14,100	2,570	
Switzerland	470 ^r	241 r	202	120	8,200	2,430	9,930	2,670	
Taiwan	23 ^r	8 r			1,520	136	470	59	
Ukraine	r	r			65	14	6	4	
United Kingdom	142 r	108 r	410	256	2,510	836	2,050	504	
Other	185 r	133 r	145	162	5,030 r	470	1,840	898	
Total	4,180 r	2,040 r	4,910	2,130	591,000 r	78,000	723,000	77,600	

(Thousand carats and thousand dollars)

Revised. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Harmonized Tariff Schedule of the United States codes 7105.10.0011 and 7105.10.0015 for natural diamond.

³Harmonized Tariff Schedule of the United States codes 7105.10.0020, 7105.10.0030, and 7105.10.0050 for synthetic diamond.

⁴Customs value.

Source: U.S. Census Bureau.

TABLE 4

U.S. REEXPORTS OF INDUSTRIAL DIAMOND STONES, BY COUNTRY¹

(]	Thousand	carats	and	thousand	dol	lars)
----	----------	--------	-----	----------	-----	------	---

	Industrial unworked diamonds ²					
	2012	2	20)13		
Country	Quantity	Value ³	Quantity	Value ³		
Belgium	427 ^r	8,560 ^r	377	7,570		
Brazil	445 ^r	294 ^r	450	381		
Canada	8,480 ^r	7,470 ^r	3,430	3,180		
Germany	62 ^r	483 ^r	29	287		
Hong Kong	35 ^r	695 r	14	624		
Israel	3	64	27	162		
Japan	6,130 ^r	10,800 r	5,750	9,020		
Korea, Republic of	1,040 r	1,580 r	1,270	2,150		
South Africa	8	37 ^r				
United Kingdom	293 ^r	3,780 ^r	204	2,740		
Other	2,820 r	2,700 ^r	3,930	3,850		
Total	19,700 r	36,400 r	15,500	30,000		

^rRevised. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Harmonized Tariff Schedule of the United States code 7102.21.0000. ³Free alongside ship (f.a.s.) value.

U.S. EXPORTS AND REEXPORTS OF INDUSTRIAL DIAMOND DUST, GRIT, AND POWDER, BY $\operatorname{COUNTRY}^1$

	Synthetic ²				Natural ²				
	201	2	2	013	20	2012		3	
Country	Quantity	Value ³	Quantity	Value ³	Quantity	Value ³	Quantity	Value ³	
Exports:									
Austria	3,490 ^r	1,230	1,430	599					
Belgium	440	111	121	25	35	38	55	140	
Brazil	3,800	1,010	2,610	732	15	4			
Canada	3,470	2,420	2,600	1,890	1,990	1,950	1,220	978	
Germany	2,610	843	699	198	60	33	27	28	
Hong Kong	212	110	198	127	101	43	57	108	
India	2,910	1,080	2,280	827	9	13			
Ireland	40,100	15,500	22,900	8,490	40	66	43	69	
Israel	25	26	801	323	431	95	46	57	
Italy	4,320	899	5,270	1,510		3			
Japan	39,100	18,800	25,100	12,600	47	69			
Korea, Republic of	14,700	10,500	15,400	9,330	1,840	429	1,730	342	
Mexico	862	383	540	199	546	295	541	407	
Singapore	1,350	1,940	658	1,950			2	3	
Spain	86	23	24	6					
Switzerland	12,200	10,800	15,700	13,800	486	453	153	103	
Taiwan	5,130	2,520	6,440	4,400					
Thailand	4,600	1,420	6,560	2,000			66	22	
United Kingdom	2,300	656	1,790	698	797	482	179	147	
Other	7,200 r	2,900	18,800	7,970	98 r	125 ^r	83	69	
Total	149,000 r	73,200	130,000	67,600	6,500	4,100	4,210	2,470	
Reexports:									
Belgium	462 ^r	31 ^r	432	11	44	124 ^r	49	221	
Brazil	460 r	217	450	254		4 ^r			
Canada	10,500 r	3,510	4,650	683	2,610	4,580 ^r	1,850	2,890	
Germany	123 r	11 ^r	56	8		33 ^r	4	35	
Ireland	722 ^r	389	2,090	821	7	84 ^r	10	86	
Italy	- 18	4				3 ^r			
Japan	6,170 ^r	1,800	5,750	1,300	143 ^r	313 ^r	152	271	
Korea, Republic of	2,880 ^r	272	3,000	708	38	482 ^r	15	359	
Mexico	1,010 ^r	122	1,180	221	37	390 ^r	16	439	
United Kingdom	1,090 ^r	11	383	19	143	564 ^r	70	266	
Other	2,830 r	890 r	1,700	947	40	769 ^r	49	446	
Total	26,200 r	7,260	19,700	4,970	3,070	7,350 ^r	2,210	5,010	
Grand total	175,000 r	80,500 r	150,000	72,600	9,570 ^r	11,400 r	6,420	7,480	

(Thousand carats and thousand dollars)

^rRevised. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Harmonized Tariff Schedule of the United States codes 7105.10.0025 for synthetic and 7105.10.0010 for natural diamond.

³Free alongside ship (f.a.s.) value.

Source: U.S. Census Bureau.

DIAMONDS (NATURAL): ESTIMATED WORLD PRODUCTION, BY COUNTRY AND TYPE^{1, 2}

(Thousand carats)

Country and type ³	2009	2010	2011	2012	2013
Gemstones:					
Angola ⁴	8,310	7,530	7,500	7,500	8,420
Australia ⁵	312 ^r	200 ^r	157 ^r	184 ^r	235
Botswana ⁶	12,400	15,400	16,000	14,400	16,200
Brazil, unspecified ⁷	21	25	46	46	49
Cameroon, unspecified					3 8
Canada, unspecified	10,900 r	11,800 ^r	10,800 r	10,500 ^r	10,600
Central African Republic ^{9, 10}	249	241	259	293	
China, unspecified	46	17	(11)	2	1
Congo (Brazzaville), unspecified	68 ^r	381 ^r	77 ^r	52 ^r	56
Congo (Kinshasa) ¹²	4,260 r	4,030 r	3,850 r	4,300 r	3,140
Ghana, unspecified	376	334	302	233	169
Guinea ¹⁰	557	299	243	213	162
Guyana	97	46	51	44	60
India ¹³	3 ^r	5	3	7	10
Indonesia ¹⁴	2 ^r				
Lesotho, unspecified	92	109	224	479	414
Liberia ¹⁵	17 ^r	16 ^r	25 ^r	25 ^r	32
Namibia, unspecified	1,190	1,690	1,260	1,630	1,690
Russia ¹⁶	19,500 ^r	19,500 ^r	19,700 ^r	19,600 ^r	21,200
Sierra Leone ¹⁷	241	263	214	406	457
South Africa ¹⁰	4,910 ^r	7,090 ^r	5,640 r	5,660 r	6,510
Tanzania ¹⁸	155	60	35	108	153
Togo, unspecified	(11)	(11)	(11)	(11)	(11)
Venezuela ¹⁹	3	1			
Zimbabwe ²⁰	96 ^r	844 ^r	850 ^r	1,210 ^r	1,040
Total	63,800 r	69,900 ^r	67,200 ^r	66,800 r	70,600
Industrial:					
Angola ⁴	924	836	833	833	936
Australia ⁵	15,300 r	9,800 r	7,700 ^r	9,000 r	11,500
Botswana ⁶	5,320	6,610	6,870	6,170	6,960
Central African Republic ¹⁰	62	60	65	73	
Congo (Kinshasa) ¹²	17,000 ^r	16,100 ^r	15,400 r	17,200 ^r	12,500
Guinea ¹⁰	139	75	61	53	40
India ¹³	7	13	9	20	27
Indonesia ¹⁴	9 r				
Liberia ¹⁵	11	11	17	17	21
Pussia ¹⁶	15 300 r	15 300 r	15 500 ^r	15 400 ^r	16 700
Sierra Leone ¹⁷	160	13,500	143	13,400	152
Stella Leone	1 230 r	1 770 r	1 410 r	1 4 2 0 T	1.630
Tamania ¹⁸	1,250	1,770	1,410	1,420	1,050
I anzania		11	0	19	21
Venezuela ²⁰	5	1 7 500 r			
Zimbabwe ²⁰	867 1	/,590 ¹	/,650 *	10,900 '	9,370
Iotal	56,400 *	58,400 1	55,600 *	61,200 *	59,900
Grand total, uniounded	120.224	120.01/	122.829	127.902	1.30.482

^rRevised. -- Zero.

¹Estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Includes data available through August 15, 2014.

³In addition to countries listed, Belarus, Germany, Ireland, Nigeria, the Republic of Korea, and Sweden produced natural diamond, but information is inadequate to formulate reliable estimates of output levels.

⁴About 90% gem quality and 10% industrial quality.

⁵About 2% gem quality and 98% industrial quality.

⁶About 70% gem and near gem quality and 30% industrial quality.

⁷Figures represent officially reported diamond output plus official Brazilian estimates of output by nonreporting miners.

TABLE 6—Continued DIAMONDS (NATURAL): ESTIMATED WORLD PRODUCTION, BY COUNTRY AND TYPE^{1, 2}

⁸From artisanal mining.

⁹Includes artisanal mining.

¹⁰About 80% gem quality and 20% industrial quality.

¹¹Less than $\frac{1}{2}$ unit.

¹²About 20% gem quality and 80% industrial quality.

¹³About 27% gem quality and 73% industrial quality.

¹⁴About 17% gem quality and 83% industrial quality.

¹⁵About 60% gem quality.

¹⁶About 56% gem quality.

¹⁷From 2009 to 2011, production was estimated to be about 60% gem quality and 40% industrial quality. In 2012 and 2013, production was estimated to be about 75% gem quality and 25% industrial quality.

¹⁸About 85% gem quality and 15% industrial quality.

¹⁹About 40% gem quality and 60% industrial quality.

²⁰About 10% gem quality and 90% industrial quality.