



# 2009 Minerals Yearbook

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## DIAMOND

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# DIAMOND, INDUSTRIAL

By Donald W. Olson

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In 2009, U.S. synthetic diamond production was estimated to be 91.0 million carats with an estimated value of \$65.1 million. U.S. imports of all forms of industrial diamond totaled about 247 million carats valued at almost \$59.5 million, while exports totaled more than 67.0 million carats valued at almost \$33.4 million. The estimated U.S. apparent consumption of all forms of industrial diamond was 305 million carats with an estimated value of \$108 million.

Diamond is best known as a gemstone, but some of its unique properties make it ideal for many industrial and research applications as well. Current information on gem-grade diamond can be found in the U.S. Geological Survey (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. Production and consumption quantities and values reported are estimated to avoid disclosing company proprietary data and still provide useful data on the overall market. Trade data in this report are from the U.S. Census Bureau. All percentages in the report were computed using unrounded data. The USGS does not conduct surveys of either domestic polycrystalline diamond (PCD) producers or domestic chemical vapor deposition (CVD) diamond producers for quantity or value of annual production. Also, trade and consumption quantity or value data are not available for PCD or for CVD diamond.

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 it is the hardest substance known, 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, diamond has proven to be more cost-effective in many industrial processes because it cuts faster and lasts longer than alternative abrasive materials (Boucher, 1997, p. 26.6). 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 synthetic and natural 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 (Boucher, 1996). For these reasons, synthetic diamond accounts for about 94% of the industrial diamond used in the United States and about 99% of the industrial diamond used in the world.

## Legislation and Government Programs

There is no remaining inventory of the stockpiled industrial diamond in the National Defense Stockpile (NDS), which is managed by the Defense National Stockpile Center (DNSC), Defense Logistics Agency. The last stockpiled industrial diamond was industrial diamond stone which was completely sold during 2008 (Lough, 2008). At the present time, there are no plans to stockpile any inventory of industrial diamond in the NDS.

## 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 2009 survey, one of the three industrial diamond recycling firms did not report data that they deemed to be proprietary. To protect the proprietary data of other producers and recyclers, only estimates of U.S. primary and secondary output are provided in this review.

As one of the world's leading producers of synthetic industrial diamond, the United States accounted for an estimated output of 91 million carats valued at more than \$65.1 million in 2009. U.S. synthetic industrial diamond output estimates have been revised downward for 2005 through 2008 in table 6 because production data for one company had been improperly overestimated during those years. Only two U.S. companies produced synthetic industrial diamond during the year—Diamond Innovations, Inc., Worthington, OH, and Mypodiamond, Inc., Smithfield, PA.

In 2009, 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 2009, an estimated 33.9 million carats of used industrial diamond worth about \$17.2 million were 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; most of this material was recovered from within the production operations of the PCD-producing companies.

The recovery and sale of industrial diamond was the principal business of three U.S. companies in 2009—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.

There were no commercially operated diamond mines in the United States during 2009. The last commercially operated diamond mine in the United States was the Kelsey Lake diamond mine, located near Fort Collins, CO, which closed in 2002 and was fully reclaimed.

Canadian diamond mining industry success stimulated some interest in exploration for diamond deposits in areas of the United States with similar geologic settings and terrain. These areas are located in Alaska, Colorado, Minnesota, Montana, and Wyoming (Associated Press, 2002, 2004; Diamond Registry Bulletin, 2005). Although exploration and field studies have found a number of large diamond deposits, none have attracted long-term investors and been able to open a commercially feasible mine thus far.

## Consumption

The United States remained the world's leading market for industrial diamond in 2009. Based on production estimates and trade data, apparent U.S. consumption of industrial diamond during the year decreased by about 44% to an estimated 305 million carats valued at \$108 million. This apparent consumption was the combination of 251 million carats of diamond bort, grit, dust, and powder valued at \$36.6 million and 54.6 million carats of diamond stone valued at \$71.9 million. These large decreases were because of the negative impact of the economic recession on industrial sectors that consume industrial diamond.

The major consuming industries of industrial diamond in the United States during 2009 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, stone cutting and highway building/repair together made up the largest demand for industrial diamond. Research and high-technology 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 minerals, natural gas, and oil. Other applications of diamond bits and reaming shells include foundation testing, masonry drilling, and inspecting concrete. 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/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 much as 1 meter in diameter.

Loose powders made with synthetic diamond for polishing are used primarily to finish cutting tools, gemstones, jewel bearings, optical surfaces, 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.

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. The use of PDCs, PDSs, and matrix-set synthetic diamond grit for drilling bits and reaming shells has increased in recent years. 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.

In the early 2000s, Apollo Diamond, Inc., near Boston, MA, developed and patented a method for growing extremely pure, gem-quality diamond with flawless crystal structure by CVD. The CVD technique transforms carbon into plasma, which then is precipitated onto a substrate as diamond. CVD has been used for more than a decade to cover large surfaces with microscopic diamond crystals, but until this process was developed, no one had discovered the combination of temperature, gas composition, and pressure that resulted in the growth of a single diamond crystal. Since CVD diamond precipitates as nearly pure, almost flawless diamond, they are difficult to distinguish from natural diamond by most tests (Davis, 2003). CVD diamond's highest value, besides its use as gemstones, is as a material for advanced technological uses. CVD diamond could be used to make extremely powerful lasers; to miniaturize cellular telephones and vastly improve data storage capacity for electronic devices; to create frictionless medical replacement joints; or in coatings for cars or other devices that would not scratch or wear off. The greatest potential use for CVD diamond could be in computer technology (Maney, 2005). For diamond to be an economical material for use as a semiconductor, it must be affordably grown in large wafers. As this technology becomes more fully developed, CVD diamond could possibly be grown relatively inexpensively. Growth of CVD diamond is limited only by the size of the seed placed in the diamond growing

chamber. Diamond computer chips are more durable because they can work at temperatures up to 1,000 °C, while silicon computer chips stop working at about 150 °C. This means that diamond computer chips will probably work at a much higher frequency or faster speed (Diamond Registry Bulletin, 2003).

In 2004, researchers at the Carnegie Institution of Washington's Geophysical Laboratory published a study showing that researchers grew diamond crystals by a special CVD process at very high growth rates. They were able to grow gem-sized crystals in a day—a growth rate 100 times faster than other methods used before. This is a new way of producing diamond crystals for such new applications as diamond-based electronic devices and next generation cutting tools (Willis, 2004). By early 2005, the Carnegie Institution's Geophysical Laboratory and the University of Alabama jointly had developed and patented the CVD process and apparatus to produce 10-carat, ½-inch thick single diamond crystals at very rapid growth rates (100 micrometers per hour). This faster CVD method uses microwave plasma technology and allows multiple crystals to be grown simultaneously. This size is about five times that of commercially available lab-created diamonds produced by high pressure and high temperature (HPHT) methods and other CVD techniques (Willis, 2004; Carnegie Institution of Washington, 2005; Science Blog, 2005). Both Apollo Diamond and the Carnegie Institution have noted that their diamonds produced by the CVD method are harder than natural diamonds and diamonds produced by HPHT methods.

Research at the Carnegie Institution continued improving the microwave plasma CVD method developing a process to anneal the diamonds at temperatures up to 2,000 °C using a microwave plasma at pressures below atmospheric pressure. In this process, the diamond crystals, which are originally yellow-brown if produced at very high growth rates, are turned colorless or light pink. This low-pressure/high-temperature annealing process enhances the optical properties of this rapid-grown CVD single crystal diamond, and the size of the crystals that can be treated is not limited. This process is thought to produce better synthetic diamonds for high pressure devices and window materials with improved optical properties in the ultraviolet to infrared range. These high-quality, single-crystal diamonds likely will have a wide variety of applications, such as using the diamond crystals as anvils in high-pressure research, or optical uses that take advantage of the outstanding transparency of diamond. Another application might be in quantum computing, by utilizing vacancy centers in the diamond's crystal lattice for storing quantum information (Carnegie Institution for Science, 2008).

## Prices

Natural and synthetic industrial diamonds differ significantly in price. Natural industrial diamond normally has a more limited range of values. The price varies from an average of \$1 per carat for bort size material to about \$2.50 to \$10 per carat for most stones, with some larger stones selling for up to \$200 per carat.

Synthetic industrial diamond has a much wider price range than natural diamond. Prices of synthetic diamond vary according to particle strength, size, shape, crystallinity, and the absence or presence of metal coatings. In general, the prices for synthetic diamond dust, grit, and powder used in grinding and

polishing range from as low as \$0.26 to \$1.70 per carat. Strong and blocky material for sawing and drilling sells for \$1.00 to \$3.50 per carat. Large synthetic crystals with excellent structure for specific applications sell for many hundreds of dollars per carat (Law-West, 2002, p. 23.8).

## Foreign Trade

The United States continued to lead the world in industrial diamond trade in 2009; imports were received from 35 countries, exports were sent to 42 countries, and reexports were sent to 35 countries (tables 1–4). 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 there has been no domestic production of natural diamond.

During 2009, U.S. imports of industrial-quality diamond stones (natural and synthetic) decreased by 56% from those of 2008 to about 1.4 million carats valued at about \$18.7 million (table 1). The average value of these industrial-quality diamond stone imports was \$13.30 per carat. Imports of diamond dust, grit, and powder (natural and synthetic) decreased by 50% from those of 2008 to 246 million carats valued at about \$40.8 million (table 2). The average value of these industrial diamond dust, grit, and powder imports was \$0.17 per carat.

Reexports account for a significant portion of total exports/reexports; therefore, exports and reexports are listed separately in tables 3 and 4 so that U.S. trade and consumption can be calculated more accurately. During 2009, there were no U.S. exports of industrial diamond stones, compared with exports of 4,000 carats valued at \$47,000 for 2008. U.S. reexports of industrial diamond stone decreased by 26% from those of 2008 to 947,000 carats valued at \$17.5 million and an average value of \$18.50 per carat (table 3). U.S. exports of industrial diamond dust, grit, and powder (natural and synthetic) decreased by 42% from those of 2008 to 67 million carats valued at \$33.4 million and an average value of \$0.50 per carat. Reexports of industrial diamond dust, grit, and powder (natural and synthetic) increased by 16% from those of 2008 to 9.89 million carats valued at \$4.24 million and an average value of \$0.43 per carat (table 4).

## World Industry Structure

In 2009, industrial diamond was produced in 30 countries (tables 5, 6). Total industrial diamond output worldwide was estimated by the USGS to be about 4.4 billion carats valued between \$1.65 and \$2.50 billion. Natural industrial diamond production worldwide was estimated to be more than 55 million carats, a 19% decrease compared with that of 2008. Russia was the leading producing country, followed by Congo (Kinshasa) and Australia, in descending order of quantity. These three countries produced more than 73% of the world's natural industrial diamond (table 5). Synthetic industrial diamond production worldwide was estimated to be more than 4.4 billion carats, a slight decrease compared with that of 2008. 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 (table 6).

In addition to the countries listed in table 6, Germany and the Republic of Korea produced synthetic diamond, but specific data on their output could not be confirmed. In 2009, 97% of the total global 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.

## World Review

Global diamond production decreased 17% during 2009 to 129 million carats (Mct). The world's leading rough diamond producers in decreasing order of quantity produced were: Russia, producing 32.8 Mct or 25% of total world production; Botswana, with 31.0 Mct or 24%; Congo (Kinshasa), producing 18.0 Mct or 14%; Canada, with 10.9 Mct or 9%; Australia, with 10.8 Mct or 8%; Angola, with 9.0 Mct or 7%; South Africa, with 5.5 Mct or 4%; and other countries, with 10.7 Mct or 8% (table 5). As the global recession deepened during the first quarter of 2009, many of the world's alluvial mines closed, and many exploration projects were suspended or severely reduced. De Beers Group, ALROSA Co. Ltd., and BHP Billiton were the three leading diamond exploring companies; they accounted for 64% of the estimated \$393 million total global diamond exploration budget by 113 companies in 2009 (Metals Economics Group, 2010, p. 12–13; 2011, p. 10–13).

Worldwide in 2009, three small diamond mines and two expansion projects started up. Three of the startups were in Russia, and two were in Guinea (Metals Economics Group, 2010, p. 14).

**Canada.**— Canadian diamond production was more than 10.9 Mct with an estimated value of \$1.7 billion during 2009, a decrease of about 26% compared with that of 2008. Diamond exploration continued in Canada, with several commercial diamond projects and additional discoveries in Alberta, British Columbia, the Northwest Territories, Nunavut, Ontario, and Quebec. In 2009, Canada produced 8.8% of the world's combined natural gemstone and industrial diamond output.

The Ekati Diamond Mine, Canada's first operating commercial diamond mine, completed its 11th full year of production in 2009. Ekati produced 4.2 Mct of diamond from 5.10 million metric tons (Mt) of ore. BHP Billiton Ltd. has an 80% controlling ownership in Ekati, which is in the Northwest Territories. Ekati has estimated remaining reserves of 38.5 Mt of ore in kimberlite pipes that contain 18.3 Mct of diamond. BHP Billiton projected the remaining mine life to be 13 years. Approximately 21% of the Ekati 2008 diamond production is industrial-grade material (BHP Billiton Ltd., 2010, p. 10; Perron, 2011, p. 1).

The Diavik Diamond Mine, Canada's second diamond mine, also located in the Northwest Territories, completed its seventh full year of production. In 2009, Diavik produced 5.6 Mct of diamond, a decrease of 40% from the previous year's production. This lower production was a consequence of a reduced operating level at the mine intended to balance

production with lower market demand that resulted from the downturn in the economy that began in mid-2008. Diavik reacted by temporarily ceasing diamond production at the Diavik Mine between July 14 and August 24, 2009. During this time period, the Diavik Mine was placed on a care-and-maintenance schedule. At yearend 2009, Diavik estimated the mine's remaining proven and probable reserves to be 19.7 Mt of ore in kimberlite pipes containing 59.1 Mct of diamond and projected the total mine life to be 16 to 22 years. During 2009, Diavik began developing an underground mine, and construction on the underground project was substantially completed during 2009. First ore was expected during the first quarter of 2010, with full production expected in 2013. The mine is an unincorporated joint venture between Diavik Diamond Mine Inc. (60%) and Harry Winston Diamond Mines Ltd. (40%) (Diavik Diamond Mine Inc., 2010; Perron, 2011, p. 2).

Canada's third diamond mine, the Jericho Diamond Mine, is located in Nunavut and was owned by Tahera Diamond Corp. Tahera estimated the Jericho Diamond Mine's reserves to be about 5.5 Mt of ore grading 0.85 carats per ton. The Jericho Diamond Mine experienced startup problems related to ore mining and processing. The mine also has suffered financial problems owing to the cost of transporting supplies to the mine site, higher operational costs, higher oil prices, and appreciation of the Canadian dollar versus the U.S. dollar. All of these problems combined to force the company to enter into protection under Canada's "Companies' Creditors Arrangement Act" on January 16, 2008, and the mine suspended production on February 6, 2008. As a result, the mine's 2008 production was only 118,000 carats. At yearend 2009, the Tahera was finalizing arrangements to sell all its Jericho mine assets (Perron, 2011, p. 2).

The Snap Lake Mine, which is wholly owned by De Beers Canada Inc., is in the Northwest Territories. The Snap Lake deposit is a tabular-shaped kimberlite dike rather than the typical kimberlite pipe. The dike is 2.7 meters thick and dips at an angle of 15°. The deposit was mined using a modified room and pillar underground mining method in 2009. The Snap Lake Mine started mining operations in October 2007, reached commercial production levels in the first quarter of 2008, and officially opened June 25, 2008. The mine was expected to produce 1.4 million carats per year of diamond, and the mine life was expected to be about 20 years. De Beers suspended production for 6 weeks in July and August 2009. This production suspension was scheduled to align production levels with market demand. The mine's production for the year amounted to 440,000 carats for a recovered grade of 1.25 carats per ton (Perron, 2011, p. 2, 3).

The Victor Mine, which also is wholly owned by De Beers Canada, is in northern Ontario on the James Bay coast. The Victor kimberlite consists of two pipes with surface area of 15 hectares (37.1 acres). The Victor Mine initiated mining operations at the end of December 2007 and was officially opened on July 26, 2008. The Victor reportedly has 27.4 Mt of ore with average ore grade of 0.23 carats per ton estimated minable reserves. At full capacity, the open pit mine was expected to produce 600,000 carats per year, and the mine

life was expected to be about 12 years. De Beers suspended mine production for 6 weeks in July and August 2009 to align production with market demand. In 2009, the mine's production was 696,000 carats valued at \$244 million and had an average recovery grade of 0.33 carats per ton (Perron, 2011, p. 3).

**Guinea.**—The Mandala alluvial mine, owned by Stellar Diamonds, was producing with positive cash flow at 60% of capacity by yearend 2009. During 2010, the mine's output was expected to be 140,000 carats. Stellar estimated that the deposit contains 536,000 carats of diamond in 1.41 Mt of resources, grading 0.38 carats per ton (Metals Economics Group, 2010, p. 14–15).

Another alluvial mine, Bomboko, owned by West African Diamonds, had ramped up to production of 1,500 carats of diamond from 35,000 tons of resources per month by October 2009. Visual inspection of stones produced indicated that about 60% was gem quality and 40% was industrial grade. West African estimated that the deposit contains 750,000 carats of diamonds in 25 Mt of resources grading 0.03 carats per ton (Metals Economics Group, 2010, p. 14–15).

**Russia.**—In 2009, Russia was again the world's leading producer of combined natural gemstone and industrial diamonds as it has been every year since 2004. Russian natural diamond production was 32.8 Mct with an estimated value of \$2.34 billion, a decrease of about 11% compared with that of 2008 (Metals Economics Group, 2011, p. 12).

The largest mine that came online in 2009 was the underground development of the Arkangelskaya pipe at the Lomonosov Mine in northwestern Russia. Lomonosov started mining the Arkangelskaya pipe in September at 1 million metric tons per year (Mt/yr) of ore and was estimated to have an optimum production capacity of 4 Mt/yr of ore. Lomonosov is 95% owned by Alrosa and 5% by the Government of Russia. Lomonosov was estimated to have 27.3 Mct of diamonds contained in 54.8 Mt of ore, grading at an estimated 0.5 carats per ton. The estimated mine life was 17 years, with materials coming from the Arkangelskaya and Karpinskogo-1 pipes (Metals Economics Group, 2010, p. 14–15).

The Mirny Division of Alrosa in Yakutia officially opened the Mir underground mine in August. The Mir was expected to yield 500,000 carats of diamonds from 1 Mt/yr of ore during a projected 50-year mine life. Alrosa had future plans for two additional underground operations parallel to Mir, which would provide an additional 4.5 Mt of ore (Metals Economics Group, 2010, p. 14–15).

A third new mine owned by Alrosa was the Aikhal underground mine in Yakutia. Aikhal began commercial production in December 2009. The mine reportedly was estimated to contain 1.25 Mct of diamonds in 12.5 Mt of ore grading 0.10 carats per ton. Aikhal had an estimated 25-year mine life (Metals Economics Group, 2010, p. 14–15).

## 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, imports, and apparent consumption will continue to increase as manufacturing sectors that use industrial diamond recover from the negative impact 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 (Advanced Materials & Processes, 1998). In view of the many advantages that come from increased tool life and reports that diamond film surfaces can increase durability by a factor of 50, much wider use of diamond as an engineering material is expected.

PCD for abrasive tools and wear parts will 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 will 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 a higher-temperature environment 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 such as using the diamond crystals in high-pressure research, optical applications that take advantage of the outstanding transparency of diamond, or using them in quantum computing to store quantum information in vacancy centers in the diamond's crystal lattice.

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, grit, and dust and powder is expected to remain greater than for natural diamond material. Constant-dollar prices of synthetic diamond products probably will 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.

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TABLE 1  
U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND STONES, BY COUNTRY<sup>1</sup>

(Thousand carats and thousand dollars)

Country	Natural industrial diamond stones <sup>2</sup>				Miners' diamond, natural and synthetic <sup>3</sup>			
	2008		2009		2008		2009	
	Quantity	Value <sup>4</sup>	Quantity	Value <sup>4</sup>	Quantity	Value <sup>4</sup>	Quantity	Value <sup>4</sup>
Australia	90	506	52	390	4	64	(5)	40
Belgium	79	452	9	164	--	--	(5)	30
Botswana	1,210	21,500	678	10,400	100	443	3	13
Congo (Kinshasa)	12	73	10	209	1	8	--	--
Ghana	3	43	(5)	5	--	--	--	--
India	116	187	40	39	74	665	11	146
Namibia	193	1,320	129	856	1	6	1	6
Russia	213	3,020	137	2,140	--	--	--	--
South Africa	1,050	6,790	295	3,540	16	255	7	118
Other	50 <sup>5</sup>	1,080	30	466	6	5,090	(5)	71
Total	3,010 <sup>5</sup>	34,900	1,380	18,200	202	6,540	22	423

<sup>1</sup>Revised. -- Zero.

<sup>2</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>3</sup>Includes glazers' and engravers' diamond unset, Harmonized Tariff Schedule of the United States (HTS) codes 7102.21.3000 and 7102.21.4000.

<sup>4</sup>HTS codes 7102.21.1010 and 7102.21.1020.

<sup>5</sup>Customs value.

<sup>6</sup>Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 2  
U.S. IMPORTS FOR CONSUMPTION OF DIAMOND DUST, GRIT, AND POWDER, BY COUNTRY<sup>1</sup>

(Thousand carats and thousand dollars)

Country	Synthetic <sup>2</sup>				Natural <sup>2</sup>			
	2008		2009		2008		2009	
	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>
Belgium	2,110	724	709	297	166	94	20	12
China	319,000	22,100	174,000	13,500	188	142	142	65
Germany	162	89	64	34	10	2	--	--
Hong Kong	507	246	504	157	--	--	--	--
India	1,510	898	759	384	1,260	907	744	442
Ireland	96,100	33,300	44,900	17,900	2,720	1,540	637	359
Israel	10	7	--	--	11	4	--	--
Italy	7	5	9	2	1	2	--	--
Japan	2,680	1,910	1,670	922	119	49	16	46
Korea, Republic of	28,700	4,710	7,850	1,790	34	13	4	7
Macau	338	42	13	9	--	--	--	--
Mexico	225	162	--	--	38	29	--	--
Romania	1,260	192	1,240	265	3 <sup>r</sup>	11	--	--
Russia	25,500	3,130	7,700	1,470	123	122	15	17
Switzerland	1,080	1,530	1,000	1,360	446	688	231	135
Taiwan	153	24	61	15	25	4	--	--
Ukraine	326	48	327	29	--	--	--	--
United Arab Emirates	10	6	--	--	9	7	--	--
United Kingdom	4,900	1,520	1,790	761	671	455	886	478
Other	695	370	170	140	198	338	147	201
Total	486,000	71,000	243,000	39,100	6,010	4,410	2,840	1,760

<sup>r</sup>Revised. -- Zero.

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

<sup>2</sup>Harmonized Tariff Schedule of the United States codes 7105.10.0020, 7105.10.0030, and 7105.10.0050 for synthetic and 7105.10.0011 and 7105.10.0015 for natural.

<sup>3</sup>Customs value.

Source: U.S. Census Bureau.



TABLE 3  
U.S. EXPORTS AND REEXPORTS OF INDUSTRIAL DIAMOND STONES, BY COUNTRY<sup>1</sup>

(Thousand carats and thousand dollars)

Country	Industrial unworked diamonds <sup>2</sup>			
	2008		2009	
	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>
Exports:				
Brazil	1	33	--	--
Canada	3	13	--	--
Total	4	47	--	--
Reexports:				
Belgium	697	10,200	341	4,720
Brazil	39	276	12	87
Canada	95	924	95	670
Germany	23	645	11	326
Hong Kong	96	1,930	114	1,690
Israel	8	119	131	1,140
Japan	160	9,140	92	4,390
Korea, Republic of	15	1,020	17	860
South Africa	18	101	14	10
United Arab Emirates	1	40	16	517
United Kingdom	100	3,230	67	2,270
Other	24	333	38	814
Total	1,280	27,900	947	17,500
Grand total	1,280	28,000	947	17,500

-- Zero.

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

<sup>2</sup>Harmonized Tariff Schedule of the United States code 7102.21.0000.

<sup>3</sup>Customs value.

Source: U.S. Census Bureau.

TABLE 4  
U.S. EXPORTS AND REEXPORTS OF INDUSTRIAL DIAMOND DUST, GRIT, AND POWDER, BY COUNTRY<sup>1</sup>

(Thousand carats and thousand dollars)

Country	Synthetic <sup>2</sup>				Natural <sup>2</sup>			
	2008		2009		2008		2009	
	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>	Quantity	Value <sup>3</sup>
Exports:								
Austria	1,010	340	470	207	62	81	--	--
Belgium	402	104	253	61	24	8	15	6
Brazil	5,540	2,530	3,260	1,080	--	--	11	5
Canada	4,570	3,320	2,950	1,970	408	1,010	191	440
Germany	1,640	588	1,600	524	207	107	22	20
Greece	393	80	255	45	13	8	--	--
Hong Kong	326	226	15	11	14	37	36	107
India	2,070	1,070	2,410	998	157	32	59	44
Ireland	34,700	12,500	16,000	5,660	211	281	47	76
Israel	50	9	4	5	1	3	--	--
Italy	5,540	1,910	4,010	1,350	64	42	--	--
Japan	19,000	8,790	10,100	4,970	14	22	23	58
Korea, Republic of	12,200	6,320	6,010	3,550	417	216	20	14
Mexico	576	244	216	76	450	311	259	125
Singapore	578	732	745	1,660	43	114	14	42
Spain	58	11	199	44	--	--	--	--
Switzerland	8,460	7,010	6,580	4,820	479	279	205	124
Taiwan	3,270	1,180	2,340	982	112	45	27	17
Thailand	5,560	2,800	3,880	1,280	18	9	4	3
United Kingdom	2,230	821	2,460	819	412	530	212	202
Other	4,260	1,780	1,810	975	469	1,060 <sup>r</sup>	369	998
Total	112,000	52,400	65,500	31,100	3,580	4,200	1,510	2,280
Reexports:								
Belgium	127	91 <sup>r</sup>	74	33	264	457	81	192
Brazil	377	180 <sup>r</sup>	557	117	2	7	--	--
Canada	2,730	1,840	2,180	1,220	127	195 <sup>r</sup>	24	81
Germany	79	94	10	22	7	20 <sup>r</sup>	11	32
India	--	--	48	15	--	--	--	--
Ireland	1,480	754	825	467	2	7	18	14
Italy	140	38	--	--	--	--	--	--
Japan	1,940	503 <sup>r</sup>	3,560	1,340	11	33	--	--
Korea, Republic of	365	173	373	83	--	--	--	--
Mexico	107	104	157	56	23	42	20	45
United Kingdom	152	104 <sup>r</sup>	115	73	183	147	7	13
Other	369	224 <sup>r</sup>	1,830	437	40 <sup>r</sup>	54	4	4
Total	7,860 <sup>r</sup>	4,100	9,720	3,860	659 <sup>r</sup>	962 <sup>r</sup>	165	381
Grand total	120,000	56,500	75,200	34,900	4,230	5,160	1,680	2,660

<sup>r</sup>Revised. -- Zero.

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

<sup>2</sup>Harmonized Tariff Schedule of the United States codes 7105.10.0025 for synthetic and 7105.10.0010 for natural.

<sup>3</sup>Customs value.

Source: U.S. Census Bureau.

TABLE 5  
NATURAL DIAMOND: WORLD PRODUCTION, BY COUNTRY AND TYPE<sup>1,2,3</sup>

(Thousand carats)

Country and type <sup>4</sup>	2005	2006	2007	2008	2009
<b>Gemstones:</b>					
Angola	6,371	8,258	8,732	8,016 <sup>r</sup>	8,100
Australia	8,577	7,305	231	273	60 <sup>e</sup>
Botswana <sup>e</sup>	23,900	24,000	25,000	25,000	24,000
Brazil <sup>e</sup>	208	181	182	182 <sup>r</sup>	182 <sup>5</sup>
Canada	12,314	13,278	17,144	14,803	10,946
Central African Republic <sup>e</sup>	300	340	370	302 <sup>r</sup>	300
China <sup>e</sup>	100	100	100	100	100
Congo (Kinshasa)	7,000	5,800 <sup>r</sup>	5,700 <sup>r</sup>	4,200 <sup>r</sup>	3,600
Côte d'Ivoire <sup>e</sup>	210	210	210	210	210
Ghana	810	780	720 <sup>e</sup>	520 <sup>e</sup>	500 <sup>e</sup>
Guinea	440	380	815	2,500 <sup>e</sup>	2,400
Guyana	357	341	269	169 <sup>r</sup>	179
Lesotho	52	231	454	450 <sup>e</sup>	450 <sup>e</sup>
Namibia	1,902	2,400	2,266 <sup>r</sup>	2,435 <sup>r</sup>	2,300
Russia <sup>e</sup>	23,000	23,400	23,300	21,925 <sup>5</sup>	17,791 <sup>5</sup>
Sierra Leone	401 <sup>r</sup>	362 <sup>r</sup>	362 <sup>r</sup>	223 <sup>r</sup>	200 <sup>e</sup>
South Africa <sup>e</sup>	6,400	6,100	6,100	5,200	2,400
Tanzania <sup>e</sup>	185	230	239	202 <sup>r</sup>	150
Venezuela <sup>e</sup>	46	45	45	45	45
Zimbabwe <sup>e</sup>	160	160	100	100	100
Other <sup>6</sup>	109	70	65	105 <sup>r</sup>	126
<b>Total</b>	<b>92,800</b>	<b>94,000<sup>r</sup></b>	<b>92,400<sup>r</sup></b>	<b>87,000</b>	<b>74,100</b>
<b>Industrial:</b>					
Angola <sup>e</sup>	708	918	970	900	900
Australia	25,730	21,915	18,960	15,397 <sup>r</sup>	10,700
Botswana <sup>e</sup>	8,000	8,000	8,000	8,000	7,000
Brazil <sup>e</sup>	600	600	600	600	600
Central African Republic <sup>e</sup>	80	85	93	75 <sup>r</sup>	60
China <sup>e</sup>	960	965	970	1,000	1,000
Congo (Kinshasa)	28,200	23,100 <sup>r</sup>	22,600 <sup>r</sup>	16,700 <sup>r</sup>	14,400
Côte d'Ivoire <sup>e</sup>	90	90	90	90	90
Ghana <sup>e</sup>	200	190	180	130 <sup>r</sup>	120
Guinea	100	95	200	600	600 <sup>e</sup>
Russia <sup>e</sup>	15,000	15,000	15,000	15,000	15,000
Sierra Leone	267 <sup>r</sup>	241 <sup>r</sup>	241 <sup>r</sup>	149 <sup>r</sup>	100 <sup>e</sup>
South Africa <sup>e</sup>	9,400	9,100	9,100	7,700	3,100
Tanzania <sup>e</sup>	35	42	44	31 <sup>r</sup>	27
Venezuela <sup>e</sup>	69	70	70	70	70
Zimbabwe <sup>e</sup>	900	900 <sup>r</sup>	600 <sup>r</sup>	700 <sup>r</sup>	700
Other <sup>7</sup>	94	67	72	115 <sup>r</sup>	140
<b>Total</b>	<b>90,400</b>	<b>81,400<sup>r</sup></b>	<b>77,800<sup>r</sup></b>	<b>67,300<sup>r</sup></b>	<b>54,600</b>
<b>Grand total</b>	<b>183,000</b>	<b>175,000<sup>r</sup></b>	<b>170,000<sup>r</sup></b>	<b>154,000<sup>r</sup></b>	<b>129,000</b>

<sup>e</sup>Estimated. <sup>r</sup>Revised.

<sup>1</sup>World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through May 19, 2010.

<sup>3</sup>In addition to the countries listed, Nigeria and the Republic of Korea produce natural diamond and synthetic diamond, respectively, but information is inadequate to formulate reliable estimates of output levels.

<sup>4</sup>Includes near-gem and cheap-gem qualities.

<sup>5</sup>Reported figure.

<sup>6</sup>Includes Cameroon, Congo (Brazzaville), Gabon (unspecified), India, Indonesia, Liberia, and Togo (unspecified).

<sup>7</sup>Includes Congo (Brazzaville), India, Indonesia, and Liberia.

TABLE 6  
 SYNTHETIC DIAMOND: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1,2,3</sup>

(Thousand carats)

Country	2005	2006	2007	2008	2009
Belarus	25,000	25,000	25,000	25,000	25,000
China	3,800,000	3,900,000	4,000,000	4,000,000	4,000,000
Czech Republic	5	5	5	5	5
France	3,000	3,000	3,000	3,000	3,000
Ireland	60,000	60,000	60,000	60,000	60,000
Japan	34,000	34,000	34,000	34,000	34,000
Russia	80,000	80,000	80,000	80,000	80,000
South Africa	60,000	60,000	60,000	60,000	60,000
Sweden	20,000	20,000	20,000	20,000	20,000
Ukraine	8,000	8,000	8,000	8,000	8,000
United States	126,000 <sup>r</sup>	128,000 <sup>r</sup>	130,000 <sup>r</sup>	131,000 <sup>r</sup>	91,000 <sup>4</sup>
Total	4,220,000 <sup>r</sup>	4,320,000 <sup>r</sup>	4,420,000 <sup>r</sup>	4,420,000 <sup>r</sup>	4,380,000

<sup>r</sup>Revised.

<sup>1</sup>World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through May 19, 2010.

<sup>3</sup>In addition to the countries listed, Germany and the Republic of Korea also produces significant amounts of synthetic diamond, but output is not officially reported, and available information is inadequate to formulate reliable estimates of output levels.

<sup>4</sup>Reported figure.