USGS
science for a changing world

2005 Minerals Yearbook

DIAMOND, INDUSTRIAL

U.S. Department of the Interior
U.S. Geological Survey

September 2006

Diamond, Industrial

By Donald W. Olson

Domestic survey data and tables were prepared by Nicholas A. Muniz, statistical assistant, and the world production tables were prepared by Glenn J. Wallace, international data coordinator.

In 2005, U.S. synthetic diamond production was estimated to be 256 million carats with an estimated value of $257 million. U.S. imports of all forms of industrial diamond totaled about 286 million carats valued at almost $107 million, while exports totaled more than 92.5 million carats valued at almost $51.1 million. The estimated U.S. apparent consumption of all forms of industrial diamond was 441 million carats with an estimated value of $282 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.

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 (Ravi, 1994, p. 537). 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 diamond 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). It is for these reasons that synthetic diamond accounts for more than 99% of the industrial diamond used in the United States and about 87% of the industrial diamond used in the world.

Legislation and Government Programs

Congress has authorized the sale of all diamond in the National Defense Stockpile (NDS), which is managed by the Defense National Stockpile Center (DNSC). A portion of the stockpiled diamond stones was scheduled for sale in the NDS's fiscal year 2005 annual plan; however, the DNSC did not sell any industrial diamond stone during calendar year 2005. At yearend 2005, the DNSC reported an NDS remaining inventory of about 520,000 carats of industrial diamond stone with a market value of $5.2 million (Jenkins, 2005). The DNSC planned to conduct additional sales until all NDS diamond stone stocks are sold.

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 2005 survey, one of the two U.S. primary producers of industrial diamond and one of the four industrial diamond recycling firms withheld from the survey data that they deemed to be proprietary. To protect the proprietary data of other producers, 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 256 million carats valued at more than $257 million in 2005. Only two U.S. companies produced synthetic industrial diamond during the year—Diamond Innovations, Inc., Worthington, OH, and Mypodiamond, Inc., Smithfield, PA.

In 2005, nine companies also manufactured polycrystalline diamond (PCD) from synthetic diamond grit and powder. These companies were Dennis Tool Co., Houston, TX; Diamond Innovations; Novatek Inc., Provo, UT; Phoenix Crystal Corp., Ann Arbor, MI; Precorp Inc., Provo; SII Megadiamond Industries Inc., Provo; Tempo Technology Corp., Somerset, NJ; U.S. Synthetics Corp., Orem, UT; and Western Diamond Products, Salt Lake City, UT.

It is estimated that about 4.59 million carats of used industrial diamond was recycled in the United States during 2005. 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 four U.S. companies in 2005—Industrial Diamond Laboratory Inc., Bronx, NY; Industrial Diamond Powders Co., Pittsburgh, PA; International Diamond Services Inc., Houston; and National Research Co., Fraser, MI. In addition to these companies, other domestic firms may have recovered industrial diamond in smaller secondary operations.

There have been no commercially operated diamond mines in the United States since 2002. Diamond was produced at the

Kelsey Lake diamond mine, located close to the Colorado-Wyoming State line near Fort Collins, CO, for several years until April 2002. The Kelsey Lake property includes nine known kimberlite pipes, three of which have been tested and have shown that diamonds are present. The remaining six pipes have yet to be fully explored and tested for their diamond potential. Of the diamonds recovered, 35% to 50% was industrial grade. The identified resources are at least 17 million metric tons (Mt) grading an average of 4 carats per 100 metric tons (Taylor Hard Money Advisers, 2000§[1]).

Studies by the Wyoming Geological Survey have shown that Wyoming has the potential for a $1 billion diamond mining business. Wyoming has many of the same geologic conditions as Canada, and there is evidence of hundreds of kimberlite pipes in the State. Twenty diamondiferous kimberlite pipes and one diamondiferous mafic breccia pipe have been identified in southern Wyoming. Two of the largest kimberlite fields, State Line and Iron Mountain, and the largest lamproite field in the United States, Leucite Hills, are in Wyoming. Several diamond mining firms have been interested in the southern Wyoming and northern Colorado area, but the only diamond mine developed in the area thus far is the Kelsey Lake Mine (Associated Press, 2002§).

The success of Canadian diamond mines has stimulated interest in exploring for commercially feasible diamond deposits in the United States outside of Wyoming and Colorado. Australian and Canadian companies are now conducting diamond exploration in Alaska and Minnesota. Alaska has some similar geologic terrain to the Northwest Territories; in addition, certain varieties of garnet and other diamond indicator minerals as well as 17 microscopic diamonds have been found near Anchorage, AK. Two Canadian companies have invested $1 million in an exploratory drilling program. Geologists from the University of Minnesota teamed with an Australian mining company and were conducting a soil sampling program in Minnesota for mineral exploration, including diamond. The samples were being analyzed by Australia's WMC Resources Ltd. The scientists believe that there is good chance of success owing to similarities between the geology in Minnesota and Canada (Diamond Registry Bulletin, 2005).

In another exploration venture, Delta Mining and Exploration Corp. found a diamond-bearing kimberlite in an 80-acre (32.4-hectare) site known as the Homestead property near Lewistown, MT. Preliminary tests have shown the presence of microscopic diamonds. The company was planning a $700,000 soil sampling program as further exploration. Diamonds have been found in the stream beds and glacial valleys of Montana for years (Associated Press, 2004§).

Consumption

The United States remained the world's leading market for industrial diamond in 2005. Based on production estimates, trade data, and adjustments for Government stockpile sales, apparent U.S. consumption of industrial diamond during the year increased by almost 7% to an estimated 442 million carats valued at $282 million. This apparent consumption was the combination of 441 million carats of diamond bort, grit, dust and powder valued at $277 million and 1.22 million carats of diamond stone valued at $4.78 million.

The major consuming industries of industrial diamond in the United States during 2005 were construction, machinery manufacturing, mining services (exploration drilling for minerals, oil, and gas), 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. The manufacture of each automobile made in the United States consumes about 1.5 carats of 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, and polishing silicon wafers and disks drives in the computer industry (Bailey and Bex, 1995).

Diamond tools have numerous industrial functions. Diamond drilling bits and reaming shells are used principally for gas, mineral, and oil exploration. 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 drilling 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 drilling 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.

The use of polycrystalline diamond shapes (PDSs) and polycrystalline diamond compacts (PDCs) continues to increase for many of the applications cited above, including some of those that employ natural diamond. The use of PDSs, PDCs, and matrix-set synthetic diamond grit for drilling bits and reaming

[1]References that include a section mark (§) are found in the Internet References Cited section.

shells has increased in recent years. PDSs and PDCs are used in the manufacture of single- and multiple-point tools, and PDCs are used in a majority of the diamond wire-drawing dies.

Prices

Natural and synthetic industrial diamonds differ significantly in price (Boucher, 1997, p. 26.6). Natural industrial diamond normally has a more limited range of values. Its price varies from about $0.33 per carat for bort size material to about $7 to $10 per carat for most stones, with some larger stones selling for up to $200 per carat.

Synthetic industrial diamond has a much larger 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, synthetic diamond prices for grinding and polishing range from as low as $0.33 to $1.67 per carat. Strong and blocky material for sawing and drilling sells for $1.50 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 2005; imports were received from 47 countries, exports were sent to 58 countries, and reexports were sent to 65 countries (tables 1-4). Although the United States has been a major producer of synthetic diamond for decades, growing domestic markets have become more reliant on foreign sources of industrial diamond in recent years. U.S. markets for natural industrial diamond always have been dependent on imports and secondary recovery operations because there has been no domestic production of natural diamond.

During 2005, U.S. imports of industrial-quality diamond stones (natural and synthetic) increased by 19% from those of 2004 to about 2.12 million carats valued at more than $29.5 million (table 1). Imports of diamond dust, grit, and powder (natural and synthetic) increased by 18% from those of 2004 to 284 million carats valued at almost $77.3 million (table 2).

Reexports may 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 2005, U.S. exports of industrial diamond stones decreased from those of 2004 to 424 carats valued at $18,000, and U.S. reexports of industrial diamond stone decreased by 21% from those of 2004 to 1.43 million carats valued at $26.1 million (table 3). U.S. exports of industrial diamond dust, grit, and powder (natural and synthetic) increased by 8% from those of 2004 to 92.5 million carats valued at $51.1 million, and reexports of industrial diamond dust, grit, and powder (natural and synthetic) decreased by 4% from those of 2004 to 11.6 million carats valued at $8.14 million (table 4).

World Industry Structure

In 2005, industrial diamond was produced in 28 countries (tables 5-6). Total industrial diamond output worldwide was estimated by the USGS to be in excess of 644 million carats valued between $644 million and $1 billion. Natural industrial diamond production worldwide was estimated to be more than 81.0 million carats, a slight decrease compared with that of 2004. Congo (Kinshasa) was the leading producing country, followed by Australia and Russia, in descending order of quantity. These three countries produced more than 74% of the world's natural industrial diamond (table 5). Synthetic industrial diamond production worldwide was estimated to be more than 563 million carats, a slight increase compared with the previous year. The United States was the leading producing country, followed by Russia, Ireland, and South Africa, in descending order of quantity. These four countries produced about 81% 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. China may have produced more than the output listed in the table (Wilson Born, National Research Co., oral commun., 2004).

In 2005, 80% of the total global natural and synthetic industrial diamond output was produced in Ireland, Japan, Russia, South Africa, and the United States. Synthetic diamond accounted for more than 87% of global diamond production and consumption.

World Review

Canada.—The Ekati Diamond Mine, Canada's first operating commercial diamond mine, completed its seventh full year of production. In 2005, Ekati produced 3.23 million carats of diamond from 4.44 Mt of ore (BHP Billiton Ltd., 2006b). BHP Billiton Ltd. has an 80% controlling ownership in Ekati, which is in the Northwest Territories in Canada. Ekati has estimated reserves of 60.3 Mt of ore in kimberlite pipes that contain 54.3 million carats of diamond, and BHP Billiton projected the mine life to be 25 years. The Ekati mine is now producing from the Koala, Panda, and Misery kimberlite pipes. BHP Billiton is using underground mining techniques to recover diamonds from deeper portions of the Panda kimberlite pipe (BHP Billiton Ltd., 2004). Underground mining of the deeper portions of the Koala kimberlite pipe has been approved and is expected to begin in December 2007 (BHP Billiton Ltd., 2006a). Both the Koala and Panda kimberlite pipes were first open pit mined (Diamond Registry Bulletin, 2002). Approximately one-third of the Ekati diamond production is industrial-grade material (Darren Dyck, senior project geologist, BHP Diamonds, Inc., oral commun., May 27, 2001).

The Diavik Diamond Mine, also in the Northwest Territories, completed its third full year of production. In 2005, Diavik produced 8.3 million carats of diamond from its A154 North ore body and the adjacent A154 South pipe. Both pipes are located within the same pit (Diavik Diamond Mines Inc., 2006). Diavik has estimated the mine's remaining proven and probable reserves to be 29.8 Mt of ore in kimberlite pipes, containing 95.6 million carats of diamond, and projected the mine life to be 16 to 22 years (Diavik Diamond Mines Inc., 2005). The mine is an unincorporated joint venture between Diavik Diamond Mines Inc. (60%) and Aber Diamond Mines Ltd. (40%). The mine is expected to produce a total of about 107 million carats of diamond at a rate of 8 million carats per year worth about $63 per carat over the entire mine life, which began production in December 2002 (Diavik Diamond Mines Inc., 2000, p. 10-12).

Diamond exploration is continuing in Canada, with several other commercial diamond projects and additional discoveries located in Alberta, British Columbia, the Northwest Territories, the Nunavut Territory, Ontario, and Quebec. Canada produced about 7% of the world's combined natural gemstone and industrial diamond production in 2005.

Current Research and Technology

Apollo Diamond, Inc., near Boston, MA, has developed and patented a method for growing extremely pure, gem-quality diamond with flawless crystal structure by chemical vapor deposition (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, no one had discovered the combination of temperature, gas composition, and pressure that resulted in the growth of a single diamond crystal. CVD diamond precipitates as nearly 100% pure, almost flawless diamond, and therefore may not be distinguishable from natural diamond by some tests (Davis, 2003).

Apollo Diamond produced stones that range from 1 to 2 carats in 2005 and expected to expand to larger stones in the future (Maney, 2005§). The company planned to start selling diamonds in the jewelry market at costs 10% to 30% below those of comparable natural diamonds (Hastings, 2005). Apollo Diamond planned to open the Apollo Diamond Web store to the general public in 2006 (Apollo Diamond, Inc., 2005§).

CVD diamond's highest value besides its use as gemstones is as a material for high-tech uses. CVD diamond could be used to make extremely powerful lasers; to create cell phones that fit into a watch and storage devices for MP3 players that could store 10,000 movies, not just 10,000 songs; to create frictionless medical replacement joints; or as coatings for cars that would not scratch or wear out. The greatest potential use for CVD diamond is in computer technology (Maney, 2005§). For diamond to be a practical material for use as a semiconductor, it must be affordably grown in large wafers. After Apollo's process and technology are fully developed, CVD diamond could possibly be grown for prices as low as $5 per carat. CVD growth is limited only by the size of the seed placed in the diamond growing chamber. Starting with a square, wafer-like fragment, the Apollo Diamond process grows the diamond into a prismatic shape, with the top slightly wider than the base. For the past 7 years, Apollo Diamond has been growing increasingly larger seeds by chopping off the top layer of growth and using that as the starting point for the next batch. At the moment, the company is producing 10-millimeter wafers but predicts it will reach about 10 times that in the near future (Davis, 2003). Scientists have said that 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 could work at a much higher frequency or faster speed and could be placed in a high-temperature environment (Diamond Registry Bulletin, 2003§).

In early 2004, scientists 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-base electronic devices and next generation cutting tools (Willis, 2004). By early 2005, the Carnegie Institution's Geophysical Laboratory and the University of Alabama had jointly 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 pressures and high temperatures (HPHT) methods and other CVD techniques. Dr. Russell Hemley, a researcher at the Carnegie Institution stated, "High-quality crystals over 3 carats are very difficult to produce using the conventional approach. Several groups have begun to grow diamond single crystals by CVD, but large, colorless, and flawless ones remain a challenge. Our fabrication of 10-carat, half-inch, CVD diamonds is a major breakthrough" (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.

Outlook

The United States will most likely continue to be the world's leading market for industrial diamond well into the next decade. The United States also is expected to remain a significant producer and exporter of industrial diamond. The strength of U.S. demand will depend on the vitality of the Nation's industrial base and on how well the diamond life cycle cost-effectiveness compares with competing materials that initially are less expensive. 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.

The most dramatic increase in domestic use of industrial diamond is likely to be in the construction sector as the Nation builds and repairs the U.S. highway system in its implementation of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2005 (Public Law 109-59), which was passed by the U.S. House of Representatives on March

10, 2005, and by the U.S. Senate on May 17, 2005. This Act authorized appropriations for fiscal years 2005 through 2009 for Federal-aid highway programs out of the Highway Trust Fund (U.S. House of Representatives, 2005§). Demand for saw-grade diamond alone is expected to increase in 2006 if goals mandated by the Act for the repair and replacement of roads, bridges, and other components in the transportation infrastructure of the country are fulfilled.

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 (Wilson Born, National Research Co., written commun., 1998).

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.

World demand for industrial diamond will continue to increase during the next few years. Constant dollar prices of synthetic diamond products, including CVD diamond films, will decline as production technologies become more cost effective and as competition increases from low-cost producers in China and Russia.

References Cited

Advanced Materials & Processes, 1998, Diamond coating increases carbide tool life by 50x: Advanced Materials & Processes, v. 154, no. 2, August, p. 20.
Bailey, M.W., and Bex, P.A., 1995, Industrial diamond—A brief history, a long future: Finer Points, v. 7, no. 4, p. 35-39.
BHP Billiton Ltd., 2004, BHP Billiton approves Panda underground project: Melbourne, Australia, BHP Billiton Ltd. news release, May 4, 1 p.
BHP Billiton Ltd., 2006a, BHP Billiton approves Koala underground project: Melbourne, Australia, BHP Billiton Ltd. news release, June 28, 1 p.
BHP Billiton Ltd., 2006b, BHP Billiton production report for the quarter ended 31 December 2005: Melbourne, Australia, BHP Billiton Ltd. news release, January 24, 12 p.
Boucher, Michel, 1996, Overview of the diamond industry, in Industrial Minerals '96, Toronto, Ontario, Canada, October 22-23, 1996, Proceedings: Toronto, Ontario, Canada, Blendon Information Services, [unpaginated].
Boucher, Michel, 1997, Diamonds, in Canadian minerals yearbook 1996: Ottawa, Ontario, Canada, Natural Resources Canada, p. 26.1-26.19.
Carnegie Institution of Washington, 2005, Very large diamonds produced very fast: Washington, DC, Carnegie Institution of Washington news release, May 16, 1 p.
Davis, Joshua, 2003, The new diamond age: Wired, v. 11, no. 09, September, p. 96-105, 145-146.
Diamond Registry Bulletin, 2002, BHP attempts underground mining: Diamond Registry Bulletin, v. 34, no. 3, March 31, p. 3.
Diamond Registry Bulletin, 2005, Diamonds in Alaska and Minnesota?: Diamond Registry Bulletin, v. 37, no. 5, May 31, p. 3.
Diavik Diamond Mines Inc., 2000, Diavik annual social and environmental report—2000: Yellowknife, Northwest Territories, Canada, Diavik Diamond Mines Inc., 74 p.
Diavik Diamond Mines Inc., 2005, Diavik 2005 first quarter update: Yellowknife, Northwest Territories, Canada, Diavik Diamond Mines Inc. news release, May 4, 1 p.
Diavik Diamond Mines Inc., 2006, Diavik 2005 fourth quarter update: Yellowknife, Northwest Territories, Canada, Diavik Diamond Mines Inc. news release, February 9, 1 p.
Hastings, Michael, 2005, Romancing the stone: Newsweek [Asia Edition], v. CXLV, no. 7, February 14, p. 40-46.
Jenkins, James, 2005, Inventory of stockpile material: Fort Belvoir, VA, Defense National Stockpile Center, December 31, 6 p.
Law-West, Don, 2002, Diamonds, in Canadian minerals yearbook 2001: Ottawa, Ontario, Canada, Natural Resources Canada, p. 23.1-23.12.
Ravi, K.V., 1994, Technological applications of CVD diamond, in Spear, K.E., and Dismuks, J.P., eds., Synthetic diamond—Emerging CVD science and technology: New York, NY, John Wiley & Sons, Inc., p. 533-580.
Willis, F.M., 2004, Ultrahard diamonds: Today's Chemist at Work, v. 13, no. 5, May, p. 12.

Internet References Cited

Apollo Diamond, Inc., 2005, Interested in buying?, accessed June 26, 2006, via URL http://www.apollodiamond.com.
Associated Press, 2002 (March 13), Geologist sees no interest in Wyoming diamond mining, accessed July 15, 2002, at URL http://www.montanaforum.com/rednews/2002/03/14/build/mining/wyodiamond.php?nnn=2.
Associated Press, 2004 (October 19), Microscopic diamond found in Montana, accessed October 19, 2004, at URL http://www.cnn.com/2004/TECH/science/10/19/diamond.discovery.ap/index.html.
Diamond Registry Bulletin, 2003 (March), Diamond chips may replace silicon in semi-conductors, accessed September 5, 2003, at URL http://www.diamondregistry.com/News/2003/silicon.htm.
Maney, Kevin, 2005 (October 6), Man-made diamonds sparkle with potential, USA Today, accessed June 26, 2006, at URL http://www.usatoday.com/tech/news/techinnovations/2005-10-06-man-made-diamonds_x.htm.
Science Blog, 2005, Scientists patent process to create large diamond gemstones, accessed July 7, 2005, at URL http://www.scienceblog.com/cms/node/7526.
Taylor Hard Money Advisers, 2000 (April 11), McKenzie Bay International Ltd., accessed July 16, 2001, at URL http://www.mckenziebay.com/reports/jt000411.htm.
U.S. House of Representatives, 2005 (May 17), H.R. 3—Bill summary and status info, accessed September 14, 2005, at URL http://thomas.loc.gov/cgi-bin/bdquery/z?d109:HR00003:@@@D&summ2=3&TOM:/bss/d109query.html.

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.

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.

TABLE 1

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND STONES, BY COUNTRY[1]

(Thousand carats and thousand dollars)

	Natural industrial diamond stones[2]				Miners' diamond, natural and synthetic[3]			
	2004		2005		2004		2005	
Country	Quantity	Value[4]	Quantity	Value[4]	Quantity	Value[4]	Quantity	Value[4]
Australia	22	159	69	456	7	61	5	108
Belgium	105	590	49	321	94	541	32	198
Botswana	175	3,450	794	14,100	(5)	23	(5)	5
Brazil	--	--	8	130	(5)	10	5	16
Canada	6	162	(5)	11	(5)	5	1	42
China	--	--	--	--	(5)	8	--	--
Congo (Kinshasa)	20	375	87	403	2	12	4	169
Ghana	113	652	97	721	17	158	68	144
Guyana	--	--	(5)	23	--	--	(5)	13
India	3	65	81	37	--	--	33	82
Ireland	41	55	--	--	572	263	--	--
Japan	--	--	--	--	16	75	--	--
Mexico	3	19	--	--	(5)	22	--	--
Namibia	146	658	261	1,360	14	65	1	7
Russia	98	1,930	134	2,890	82	348	--	--
South Africa	198	3,460	356	7,710	2	48	4	215
Switzerland	(5)	13	5	11	(5)	36	6	16
Tanzania	1	28	2	39	--	--	--	--
United Kingdom	37	253	4	121	2	88	14	118
Other	1 r	31 r	--	--	2 r	153 r	--	--
Total	969	11,900	1,950	28,300	809	1,920	172	1,130

[r]Revised. -- Zero.

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

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

[3]HTS codes 7102.21.1010 and 7102.21.1020.

[4]Customs value.

[5]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF DIAMOND DUST, GRIT, AND POWDER, BY COUNTRY[1]

(Thousand carats and thousand dollars)

	Synthetic[2]				Natural[2]			
	2004		2005		2004		2005	
Country	Quantity	Value[3]	Quantity	Value[3]	Quantity	Value[3]	Quantity	Value[3]
Australia	149	61	55	64	170	56	32	12
Austria	30	15	32	22	--	--	--	--
Belgium	13,200	3,770	8,650	3,630	473	274	962	512
Botswana	--	--	48	34	--	--	--	--
Brazil	87	87	138	117	75	75	21	25
Canada	5	3	15	11	4	6	430	14
China	85,500	8,930	119,000	14,600	259	38	506	252
Congo (Brazzaville)	25	9	--	--	--	--	--	--
Czech Republic	--	--	10	7	--	--	--	--
France	60	78	--	--	--	--	17	29
Germany	474	228	107	37	4	3	155	41
Ghana	--	--	130	57	34	26	--	--
Greece	9	12	--	--	--	--	--	--
Hong Kong	4,300	476	4,460	1,050	--	--	--	--
India	2,480	662	1,460	547	1,050	277	275	114
Ireland	65,200	29,400	83,900	38,200	1,080	457	1,570	897
Italy	2,750	1,310	1,370	660	24	29	84	74
Japan	5,990	5,120	8,470	5,530	16	22	14	24
Korea, Republic of	8,790	3,280	10,500	4,020	21	14	45	22
Macau	238	73	--	--	12	13	2	3
Mexico	--	--	229	100	10	7	115	25
Morocco	6	4	--	--	--	--	--	--
Namibia	19	34	13	46	40	171	118	322
Romania	1,150	242	1,290	196	30	8	--	--
Russia	15,400	1,550	19,300	1,780	30	83	44	20
South Africa	2	8	--	--	--	--	61	67
Spain	--	--	616	49	--	--	1	2
Sweden	5	5	--	--	--	--	--	--
Switzerland	753	958	1,070	1,210	284	281	319	425
Taiwan	171	67	277	83	--	--	27	5
Ukraine	26,100	1,720	14,600	889	--	--	24	10
United Arab Emirates	--	--	128	56	--	--	--	--
United Kingdom	3,280	981	2,760	1,180	534	246	697	294
Total	236,000	59,100	278,000	74,200	4,160	2,090	5,520	3,190

-- Zero.

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

[2]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.

[3]Customs value.

Source: U.S. Census Bureau.

TABLE 3
U.S. EXPORTS AND REEXPORTS OF INDUSTRIAL DIAMOND STONES, BY COUNTRY[1]

(Thousand carats and thousand dollars)

	Industrial unworked diamonds[2]			
	2004		2005	
Country	Quantity	Value[3]	Quantity	Value[3]
Exports:				
Belgium	14	18	--	--
Canada	8	46	--	--
Hong Kong	501	375	--	--
United Kingdom	--	--	(4)	18
Total	523	439	(4)	18
Reexports:				
Australia	4	66	(4)	28
Belgium	805	8,560	469	7,830
Brazil	4	67	4	57
Canada	69	331	149	923
China	24	135	11	86
Germany	11	113	10	385
Hong Kong	83	907	153	1,090
India	8	224	9	628
Ireland	1	8	10	32
Israel	--	--	6	1,320
Japan	410	6,230	162	7,810
Korea, Republic of	109	1,760	28	1,410
Mexico	13	146	(4)	(4)
South Africa	11	40	15	41
Switzerland	67	173	140	180
Taiwan	13	184	8	218
United Arab Emirates	6	13	152	1,690
United Kingdom	150	1,980	94	2,190
Other	27 r	274 r	20	173
Total	1,820	21,200	1,430	26,100
Grand total	2,340	21,700	1,430	26,100

[r]Revised. -- Zero.

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

[2]Harmonized Tariff Schedule of the United States code 7102.21.0000.

[3]Customs value.

[4]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 4

U.S. EXPORTS AND REEXPORTS OF INDUSTRIAL DIAMOND DUST, GRIT, AND POWDER, BY COUNTRY[1]

(Thousand carats and thousand dollars)

	Synthetic[2]				Natural[2]			
	2004		2005		2004		2005	
Country	Quantity	Value[3]	Quantity	Value[3]	Quantity	Value[3]	Quantity	Value[3]
Exports:								
Austria	196	82	144	47	42	15	--	--
Belgium	582	259	624	197	248	271	168	78
Brazil	1,730	841	3,390	1,810	--	--	--	--
Canada	2,600	2,330	3,760	3,000	84	173	229	431
France	226	60	--	--	77	131	19	36
Germany	25,400	11,200	1,320	455	319	357	102	99
Greece	246	78	720	215	--	--	--	--
Hong Kong	303	214	500	187	47	95	17	30
India	1,470	823	1,570	745	--	--	6	15
Ireland	3,490	2,000	23,500	11,600	325	261	318	417
Israel	82	34	384	134	--	--	104	33
Italy	2,230	921	4,170	1,860	50	35	37	20
Japan	18,000	8,480	21,400	9,830	966	378	493	501
Korea, Republic of	11,400	4,380	10,100	4,560	688	226	374	131
Macau	36	38	207	172	15	15	--	--
Malaysia	525	994	112	169	17	52	60	126
Mexico	391	174	459	163	45	115	294	258
Philippines	51	12	134	103	6	9	57	14
Singapore	600	729	1,460	1,450	28	25	64	128
Spain	392	92	319	87	155	42	124	29
Switzerland	1,130	1,630	3,850	3,760	2,150	3,830	825	1,180
Taiwan	3,240	1,410	1,440	1,440	58	48	36	30
Thailand	2,930	1,140	2,650	1,020	86	23	10	15
United Kingdom	1,320	429	1,460	896	186	126	283	114
Other	746 r	395 r	4,420	1,800	746 r	1,410 r	791	1,710
Total	79,400	38,800	88,000	45,700	6,330	7,640	4,410	5,400
Reexports:								
Austria	242	122	377	117	174	26	181	36
Belgium	222	138	258	213	87	95	412	299
Brazil	8	14	59	25	9	8	123	29
Canada	1,020	1,080	965	861	89	54	110	167
Germany	728	232	705	265	596	154	456	158
India	241	69	106	31	2	3	31	13
Ireland	184	193	136	169	9	14	241	67
Italy	542	132	450	114	327	84	147	38
Japan	898	375	2,330	1,310	240	49	77	10
Korea, Republic of	1,960	829	1,710	705	2,290	505	805	189
Macau	80	46	186	194	377	60	135	21
Mexico	102	34	116	72	96	39	18	16
United Arab Emirates	--	--	--	--	--	--	600	2,540
United Kingdom	204	141	157	101	337	125	252	129
Other	702 r	313 r	318	199	412 r	207 r	185	55
Total	7,140	3,720	7,870	4,370	5,050	1,420	3,770	3,770
Grand total	86,500	42,500	95,900	50,100	11,400	9,060	8,180	9,170

[r]Revised. -- Zero.

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

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

[3]Customs value.

Source: U.S. Census Bureau.

TABLE 5

NATURAL DIAMOND: WORLD PRODUCTION, BY COUNTRY AND TYPE[1, 2, 3]

(Thousand carats)

Country and type[4]	2001	2002	2003	2004	2005
Gemstones:					
Angola[e]	4,643 r, 9	4,520	5,130 r	5,490 r	5,580
Australia	14,397 r	15,136 r	13,981 r	20,602 r	20,000 e
Botswana[e]	19,812 r, 5, 9	21,297 r, 5, 9	22,800	23,300	23,900
Brazil[e]	700	500 5	400 r	300 r, 5	300
Canada	3,716	4,937	10,756 r	12,618	12,300
Central African Republic[e]	340	312	250	263 r	265
China[e]	100 r	100 r	100 r	100 r	100
Congo (Kinshasa)	3,638	4,223 r	5,381 r	6,180 r	6,300 e
Côte d'Ivoire	207 e, 9	205 r	154 r	201 r, e	201 e
Ghana	936 e, 9	770 e, 9	675 r	690 r	760 e
Guinea	273	368	484 6	354 r, 6	411 6
Guyana	179	248	413	455 r	357
Liberia[e]	100	48	36	18	18
Namibia	1,487	1,562	1,481	2,004 r	1,900 e
Russia[e]	17,500	17,400	20,000	21,400	23,000
Sierra Leone	102 r	162 r	233 r, e	318 r, e	318 e
South Africa	4,465 r	4,351 r, 9	5,144 r	5,780 e, 9	5,780 e
Tanzania[e]	216 5	204	201	258 r	175
Venezuela	14	46	11	40 e	46 e
Other[7]	54 r	42 r	44 r	74 r	110
Total	72,900 r	76,400 r	87,700 r	100,000 r	102,000
Industrial:					
Angola[e]	516	502	570 r	610 r	620
Australia	11,779 r	18,500	17,087 r	22,709 r	20,000 e
Botswana[e]	6,604 r, 5, 9	7,100	7,600	7,800	8,000
Brazil[e]	600	600	600	600	600
Central African Republic[e]	113	104	83	88 r	88
China[e]	950	955	955	960	960
Congo (Kinshasa)	14,560	17,456	21,600	24,700 r	25,200 e
Côte d'Ivoire	102	101 r	76 r	99 r, e	99 e
Ghana[e]	234	193	225 r	230 r	253
Guinea[e]	91	123	161 6	118 r, 6	137 6
Liberia[e]	70	32	24	12	12
Russia[e]	11,700	11,600	13,000	14,200	15,000
Sierra Leone	120 r	190 r	274 r, e	374 r, e	374 e
South Africa	6,698	6,526 r	7,540 r	8,500 r, e	9,380 e
Tanzania[9]	38	36	36	46 r	30
Venezuela	28	61	24	60 e	69 e
Other[8]	91 r	81 r	82 r	121 r	190
Total	54,300 r	64,200 r	69,900 r	81,200 r	81,000
Grand total	127,000	141,000 r	158,000 r	182,000 r	183,000

[e]Estimated. [r]Revised.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through June 5, 2006.

[3]In addition to the countries listed, Nigeria produces natural diamond, but information is inadequate to formulate reliable estimates of output levels.*

[4]Includes near-gem and cheap-gem qualities.

[5]Reported figure.

[6]Exports.

[7]Includes Cameroon, Congo (Brazzaville), Gabon (unspecified), India, Indonesia, and Zimbabwe.

[8]Includes Congo (Brazzaville), India, Indonesia, and Zimbabwe.

[9]Corrections posted September 18, 2006.

TABLE 6

SYNTHETIC DIAMOND: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2, 3]

(Thousand carats)

Country	2001	2002	2003	2004	2005
Belarus	25,000	25,000	25,000	25,000	25,000
China	17,000	17,000	17,000	17,000	17,000
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	33,000	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	202,000	222,000	236,000	252,000	256,000
Total	508,000	529,000	543,000	559,000	563,000

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

[2]Table includes data available through June 5, 2006.

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