

COBALT

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Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are used to make parts for gas turbine engines. Cobalt is also used to make magnets; corrosion- and wear-resistant alloys; high-speed steels; cemented carbides (also called hardmetals) and diamond tools; catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; ground coats for porcelain enamels; pigments; battery electrodes; steel-belted radial tires; airbags in automobiles; and magnetic recording media.

The United States did not mine or refine cobalt in 2001. However, a small number of mining operations produced negligible amounts of byproduct cobalt as intermediate products. Since 1993, sales of excess cobalt from the National Defense Stockpile (NDS) have contributed to U.S. and world supplies.

World refined cobalt production continued to increase in 2001. World demand decreased, however, and annual average prices continued the downward trends that began in 1996. In spite of poor economic conditions during the second half of the year, U.S. reported consumption for the year was 6% higher than that in 2000. U.S. apparent consumption in 2001 was slightly higher than that of 2000.

Salient U.S. and world cobalt statistics for 2001 and the previous 4 years are listed in table 1. With the exception of prices and reported production from foreign countries, all quantity and value data in this report have been rounded to no more than three significant digits. Totals and percentages were calculated from unrounded numbers.

Legislation and Government Programs

The Defense National Stockpile Center (DNSC), U.S. Department of Defense, held one negotiated and nine sealed-bid cobalt offerings during fiscal year 2001 (October 1, 2000, through September 30, 2001). During this period, the DNSC sold 2,210 metric tons (t) of cobalt cathode, granules, and rondelles valued at nearly \$58 million (table 2). This represented 81% of the 2,720-t (6-million-pound) maximum allowed for sale under the fiscal year 2001 Annual Materials Plan (AMP). As of the end of the fiscal year, 346 t of cobalt had been sold, but not shipped from the stockpile (U.S. Department of Defense, 2002, p. 6, 13, 56). The AMP for fiscal year 2002 (October 1, 2001, through September 30, 2002) maintained the maximum allowable sale of cobalt at 2,720 t (Defense National Stockpile Center, 2001).

During calendar year 2001, DNSC held one negotiated and eight sealed-bid cobalt offerings and sold 1,770 t of cobalt cathode, granules, and rondelles valued at \$39.5 million. On December 31, the total uncommitted cobalt inventory held by the DNSC was 7,520 t, all of which was authorized for eventual

disposal.

Production

With the exception of negligible amounts of byproduct cobalt produced from mining operations in Missouri and Montana, the United States did not mine or refine cobalt in 2001 (Stillwater Mining Co., 2002, p. 14; U.S. Minerals Management Service, 2002¹).

In January, Formation Capital Corp. of Vancouver, British Columbia, Canada, began the formal mine permitting process for its Idaho Cobalt Project in the Idaho Cobalt Belt. As part of the process, the Forest Service, U.S. Department of Agriculture, began to prepare an environmental impact statement for the project, which was in the Salmon-Challis National Forest, in Lemhi County, ID. Formation Capital's initial plan of operations described separate underground mining operations to extract ore from the Ram and Sunshine deposits and a flotation mill to process the ore nearby. In August, Formation signed a definitive option and sale agreement with Sunshine Precious Metals, Inc., to purchase a refinery in Big Creek, ID, approximately 320 kilometers (km) (200 miles) north of the project. The hydrometallurgical refinery was designed to use pressure leaching technology and after retrofitting to process concentrates from the Idaho Cobalt project, it would have the capacity to produce approximately 2,000 metric tons per year (t/yr) of cobalt products. Formation planned to produce approximately 1,500 t/yr of cobalt as oxide, hydroxide, carbonate, and/or cathode, with initial production beginning in late 2004 (Forest Service, U.S. Department of Agriculture, 2001; Formation Capital Corp., 2001a, b; Bending, 2002, p. 2, 6, 8-9). Mining in the Idaho Cobalt Belt dates back to the late 1800s and extended until 1959, when the Blackbird Mine in Cobalt, ID, closed. Noranda Mining Inc. of Salt Lake City, UT, considered reopening the mine in the late 1970s to early 1980s, and Blackbird Metals Inc., a New York-based corporation, planned to buy and reopen the mine in the late 1980s to early 1990s. In both cases, the companies did not pursue their plans and the mine remains inactive.

During the year, U.S. Cobalt Inc. of Denver, CO, focused on obtaining funding for an exploration and development drilling program for the Madison Cobalt Project. The drilling program was necessary to bring the indicated and inferred resources on the property, near Fredericktown, MO, up to a measured status to complete a bankable feasibility study. Past production from the Madison Mine, which occurred intermittently from the mid-1800s to 1961, yielded cobalt, copper, lead, and nickel. U.S.

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

Cobalt was considering two options for the project—building a fully integrated mine-mill-refinery on the Madison property or sending ores from the mine to be custom milled at a nearby facility, and then shipping the resulting cobalt-nickel concentrate to a smelter or refinery (U.S. Cobalt Inc., 2002).

PolyMet Mining Corp. of Golden, CO, completed a prefeasibility study on its NorthMet project. The NorthMet deposit occurs in the Duluth Complex of northeastern Minnesota, which is a large layered mafic intrusion that contains, in order of relative abundance, copper, nickel, cobalt, silver, platinum-group metals, and gold. The study evaluated the potential development of the deposit by open pit mining and hydrometallurgical processing and concluded that future work and expenditures necessary to prepare a final feasibility study were justified. During the latter part of the year, PolyMet concentrated its efforts on identifying potential joint-venture partners and financing to complete the final feasibility study (PolyMet Mining Corp., 2001a, b).

In June, Cominco American Inc. acquired the rights to the Mesaba deposit under lease agreements with Longyear Mesaba Corp. and the State of Minnesota. The deposit, which was formerly called Minnamax, is a large undeveloped copper-nickel deposit in the Duluth Complex. It is estimated to contain resources of more than 700 million metric tons (Mt) of ore grading 0.46% copper and 0.12% nickel accessible by open pit mining and an additional 300 Mt of higher grade resources, which could be mined by underground methods. Cobalt and platinum-group metals and other precious metals are also present. During the year, Cominco Engineering Services Ltd. evaluated the use of a proprietary hydrometallurgical process to treat ores from the deposit (Bloomquist, 2001; Cominco Ltd., 2001; Teck Cominco Ltd., 2002, p. 19, 26).

U.S. processors made cobalt chemicals and cobalt metal powders from cobalt metal and/or cobalt-bearing scrap. U.S. Geological Survey (USGS) data on chemical and metal powder production, shipments, and stocks were derived from a monthly voluntary survey of U.S. cobalt processors. Information from this survey was used to prepare the statistics on cobalt consumption and stocks in table 3. Five of the seven cobalt processors on this survey provided data. Estimates were made for plants for which data were not provided. Two processors made extra-fine cobalt metal powder in the United States. Carolmet Cobalt Products (a division of n.v. Umicore s.a., formerly named n.v. Union Minière s.a.), made cobalt metal powder from cobalt metal at its Laurinburg, NC, plant. Osram Sylvania Inc. made cobalt metal powder from scrap in Towanda, PA. Production and shipments of cobalt metal powder are withheld to avoid disclosing company proprietary data.

In September, The Hall Chemical Co., a cobalt chemical processor with plants in Arab, AL, and Wickliffe, OH, was put up for sale by its holding company, Goldman Resources, Inc. In December, Umicore announced that it had bought the Alabama plant, which it planned to rename Umicore Specialty Chemicals-Arab. Umicore planned to use the plant to recycle spent cobalt-based catalysts from the chemical industry and to convert cobalt, nickel, and manganese metal into specialty chemicals for a wide range of applications. Hall Chemical's Ohio plant ceased operations in September (Conway, 2001; n.v. Umicore s.a., 2001).

Consumption

U.S. apparent consumption for 2001 as calculated from net imports, consumption from purchased scrap, and changes in Government and industry stocks, was slightly higher than that calculated for 2000 (see table 1). Net imports of cobalt, shipments of cobalt from the NDS, and consumption of cobalt scrap were higher in 2001 than in 2000, but there was a buildup of industry stocks by yearend.

U.S. reported consumption for 2001 was 6% higher than that for 2000. As compared with that of 2000, metallurgical industries consumed 12% more cobalt, and the total reported cobalt consumption in chemical uses was 11% lower. Reported consumption was derived by the USGS from voluntary surveys of U.S. operations. Most of the data on cobalt chemical uses were obtained from the cobalt processors survey. A second survey covered a broad range of metal-consuming companies, such as superalloy, magnetic alloy, and cemented carbide producers. For this survey, nearly 90 cobalt consumers were canvassed on a monthly or annual basis. Reported consumption and stocks data in tables 1 and 3 contain estimates to account for nonrespondents.

Prices

U.S. spot prices for cathode (minimum of 99.8% cobalt), as reported by Platts Metals Week, trended downward during the year. The highest prices, at a range of \$14 to \$15 per pound, were reported during the first 2 weeks in March and the lowest prices, at a range of \$6.50 to \$7.95 per pound, were reported in mid-November. The last year in which the Platts' spot cathode price dropped below \$7 per pound was 1988. Platts' annual average U.S. spot cathode price for 2001 was \$10.55 per pound, down by 30% from that of 2000. This price has steadily declined since 1995, when it was \$29.21 per pound (table 1).

Trends in Platts prices for Zambian cobalt (minimum 99.6% cobalt) and Russian cobalt (minimum 99.3% cobalt) were more or less parallel to those for U.S. spot cathode. The annual average of weekly prices for Zambian cobalt was \$9.94 per pound, 28% lower than that of 2000, and the annual average of weekly prices for Russian cobalt was \$9.45 per pound, 27% lower than that of 2000.

Sales prices for 99.8% cobalt cathode reported by WMC Ltd. at its Internet web site provided some market transparency and were considered a benchmark for cobalt prices (Metal Bulletin, 2000; Ryan's Notes, 2000). The trend in these prices was similar to that of Platts' U.S. spot cathode prices. WMC's highest sales price during the year was \$14.50 per pound in early March, and its lowest sales price was \$6.79 per pound for several sales during mid- to late December. In mid-November, WMC sold cobalt for delivery in January, February, and March 2002 on a formula basis—the price was to be a weighted average of WMC's monthly concluded cobalt sales prices plus a 20-cent premium (Reuters Ltd., 2001d).

OM Group, Inc. (OMG) sold grade B cobalt briquettes, with a minimum of 99.8% cobalt, on its Internet web site. Sale prices during 2001 ranged from a high of \$14.00 per pound for a sale in January to a low of \$6.75 per pound for a sale in December.

Foreign Trade

Net import reliance as a percent of apparent consumption is used to measure the adequacy of current domestic production to meet U.S. demand. Net import reliance was defined as imports minus exports plus adjustments for Government and industry stock changes. Releases from stocks, including shipments from the NDS, were counted as part of import reliance, regardless of whether they were imported or produced in the United States. In 2001, net import reliance as a percent of apparent consumption was 77%. Because there was no measurable U.S. primary cobalt production in 2001, this indicates that 77% of U.S. cobalt supply was from imports and stock releases of primary cobalt and 23% was from scrap, which would have been generated domestically or imported.

As shown in tables 4 and 5, in 2001, the United States imported 7% more cobalt than it did in 2000. Eight countries supplied 89% of U.S. imports of unwrought cobalt and cobalt in chemicals. Finland was the leading supplier, followed by Russia, Norway, Canada, the Democratic Republic of the Congo [Congo (Kinshasa)], South Africa, Belgium, and Zambia. Compared with those of 2000, cobalt imports from Belgium, Russia, South Africa, and Zambia increased and imports from Congo (Kinshasa), Finland, and Norway decreased. Cobalt imports from Canada were approximately equal during the past 2 years.

In 2001, the United States imported 76 t, gross weight, of unwrought cobalt alloys valued at \$1.8 million. Five countries supplied more than 90% of these materials—Sweden (29%), Congo (Kinshasa) (25%), Belgium (19%), the United Kingdom (11%), and Australia (7%). The United States imported 583 t, gross weight, of cobalt matte, waste, and scrap, valued at \$10.2 million. Six countries supplied nearly 90% of these materials—the United Kingdom (21%), Japan (20%), Netherlands (18%), Australia (16%), and France and Germany (6% each). The United States also imported 233 t, gross weight, of wrought cobalt and cobalt articles valued at \$13.4 million. The leading suppliers of these materials were the United Kingdom (47%), Japan (15%), France (11%), Canada and Germany (8% each), India (7%), and Belgium (4%).

U.S. exports of unwrought cobalt and cobalt contained in chemicals increased by 22% compared with those of 2000. As listed in table 6, 87% of the cobalt metal and chemical exports was shipped to seven countries—Belgium, Canada, France, Germany, Japan, the Netherlands, and the Republic of Korea. The remainder was shipped to 39 other countries.

Exports also included 741 t, gross weight, of wrought metal and cobalt articles valued at \$25.5 million. Nearly eighty-five percent of these materials was sent to 10 countries—the United Kingdom (22%), Germany (16%), Japan and Belgium (11% each), Canada (7%), the Republic of Korea (5%), and France, India, the Netherlands, and Taiwan (3% each). The remainder was shipped to 32 other countries.

World Review

World refined cobalt production increased in 2001 as compared with that of 2000. Some of the increase in production was from new producers in Australia and Uganda and some was from a net increase in production by established producers.

Refinery capacity by country is listed in table 7. Plants that processed refined cobalt, which used secondary materials (scrap) as their main source of feed or that produced a cobalt product that required further refining, were not included.

Australia.—QNI Pty. Ltd. processed lateritic ore imported from Indonesia, New Caledonia, and the Philippines at its Yabulu nickel-cobalt refinery in Townsville, Queensland, and produced 1,818 t of cobalt as cobalt oxide hydroxide, 20% more than the 1,520 t produced in 2000. In March, QNI agreed to purchase Comet Resources Ltd.'s 50% interest in the Ravensthorpe nickel project, giving QNI 100% ownership in the project. The project involved building a front-end leaching plant at Ravensthorpe on the southern coast of Western Australia. Lateritic ore from Ravensthorpe would be processed at the plant to produce an intermediate nickel-cobalt hydroxide, which would then be shipped to Yabulu for refining. During the year, QNI studied the feasibility of expanding the Yabulu refinery to accommodate the increase in feed material from Ravensthorpe. Production from Yabulu was forecast to increase to nearly 74,000 t/yr of nickel and more than 3,400 t/yr of cobalt by the end of 2005 (Comet Resources Ltd., 2001; BHP Billiton, 2002a, p. 14-15; Cobalt Development Institute, 2002b; BHP Billiton, undated§).

WMC produced cobalt in intermediate nickel-cobalt mixed sulfide at its Kwinana nickel refinery in Western Australia. The refinery processed matte produced at WMC's Kalgoorlie smelter from nickel sulfide concentrates produced from ores mined in Western Australia by WMC and other companies. WMC's mixed sulfide was refined in Norway by Falconbridge Ltd. under a tolling agreement and the resulting cobalt cathode was offered for sale by WMC on its Internet web site. In 2001, WMC sold 737 t of cobalt, as compared with 751 t sold in 2000 (WMC Ltd., 2002, p. Nickel-5).

Anaconda Nickel Ltd. continued to rectify its Murrin Murrin nickel-cobalt laterite pressure acid leaching operation east of Leonora in Western Australia as part of its efforts to ramp up nickel and cobalt production to design capacity levels. Following a strategic review of the company, Anaconda Nickel announced that it had decided to focus solely on improving the performance of the Murrin Murrin operation. Anaconda aimed to increase metal production levels, while reducing production variability. As a result, Anaconda Nickel planned to defer any further work on its Mount Margaret laterite project, which was part of its long-term "Three Nickel Province" concept, and to divest its interest in non-nickel assets. In 2001, the Murrin Murrin operation produced 1,452 t of cobalt as metal powder and briquettes, as compared with 922 t produced in 2000 (Anaconda Nickel Ltd., 2002; Metal Bulletin, 2002).

In March, Centaur Mining & Exploration Ltd., owner of the Cawse nickel-cobalt laterite pressure acid leaching operation northwest of Kalgoorlie in Western Australia, went into receivership. Although the operation was technically successful, it suffered from cost overruns during commissioning and ramp-up, cash production costs higher than those predicted by the feasibility studies, and production levels too low for economies of scale. As a result of these factors, Centaur was not able to pay off its debts. At yearend, OMG acquired Cawse's mineral rights and chemical processing capabilities. OMG planned to close the nickel refinery and ship the intermediate nickel hydroxide produced from the front end of

the plant to Finland for refining. Output from Cawse was expected to supply 8,000 t/yr of nickel to Harjavalta and 800 t/yr of cobalt to Kokkola (Metal Bulletin, 2001f; OM Group, Inc., 2001; Reuters Ltd., 2002). Capacity and production of cobalt sulfide from Cawse are not included in tables 7 and 9 because the sulfide is an intermediate product that is upgraded by other cobalt refiners.

Preston Resources Ltd. produced 379 t of cobalt from its Bulong nickel-cobalt laterite pressure acid leaching operation east of Kalgoorlie in Western Australia. Fifty-four percent of the cobalt was produced as cobalt cathode and 46% was produced as an intermediate cobalt sulfide. This represented a 10% increase as compared with the 344 t of cobalt produced in 2000, but was still below an estimated best-case output for the operation of 600 t/yr of cobalt. Cashflow shortfalls resulting from lower than budgeted production levels and the additional costs of plant rectifications have prevented Preston from making interest payments on certain loans. In December, Preston announced that it had reached an agreement with its secured creditors on the restructuring of Bulong's debt (Platts Metals Week, 2001a; Preston Resources Ltd., 2001a, b, c, d, 2002).

In addition to the production discussed above, some cobalt-bearing nickel sulfide concentrates produced in Australia were exported to OMG in Finland or Inco Ltd. in Canada to be refined.

Titan Resources NL, West Perth, Western Australia, worked on developing a metallurgical process that used bacterial oxidation to recover base metals from sulfide ores. In addition to studying the feasibility of using the heap-leach process on company ores from the Mt. Scholl and Carr Boyd deposits in Western Australia, Titan was testing the process on ore samples from WMC, Inco, and Jinchuan Non-Ferrous Metals Corp. (Titan Resources NL, 2001).

Compass Resources NL continued to work on its Browns lead-copper-cobalt-nickel sulfide project in the Northern Territory. Compass was considering open pit and underground mining of the deposit and was evaluating two options for processing the bulk sulfide concentrate that would be produced. In one option, the concentrate would be smelted in an Ausmelt Ltd. top submerged lance furnace to produce lead fume, slag, and a sulfide matte containing cobalt, copper, and nickel. The lead fume would be refined to LME grade metal and the matte would be refined to produce copper cathode, a high-purity cobalt product, and a nickel intermediate. The other option used proprietary hydrometallurgical technology partly owned by Doe Run Corp. to process the concentrate and produce LME grade lead metal, copper cathode, cobalt carbonate or metal, and a nickel intermediate. Compass planned to fast-track the project and begin production in late 2004. At yearend, Compass was working to attract a partner and to establish a funding plan to develop the project (Compass Resources NL, 2001, 2002).

In May, Black Range Minerals Ltd. received development consent from the State Government of New South Wales for its Syerston nickel-cobalt-platinum laterite project approximately 400 km northwest of Sydney. The project, which would use pressure acid leaching followed by solvent extraction-electrowinning to produce 20,000 t/yr of nickel and 5,000 t/yr of cobalt, was delayed by poor market conditions and the inability to attract a major partner by yearend (Black Range Minerals Ltd., 2001a, b).

Belgium.—Umicore converted cobalt metal, residues, and other cobalt-bearing materials into cobalt hydroxides, metal powders, oxides, and compounds at its facilities in Olen. In December, Umicore commissioned a new production line for cobalt oxide at Olen (n.v. Umicore s.a., 2002, p. 20). According to the Cobalt Development Institute, Umicore's cobalt production was 1,090 t in 2001, approximately the same as the 1,110 t produced in 2000 (Cobalt Development Institute, 2002b).

Brazil.—Cia. Niquel Tocantins produced 889 t of cobalt cathode at its refinery in Sao Miguel Paulista, Sao Paulo State, a 12% increase from production in 2000 (Cobalt Development Institute, 2002b). The refinery used lateritic nickel-cobalt ore from Niquelandia, Goias State, as feed. Because of the energy crisis in Brazil, Niquel Tocantins' plans to complete an expansion of the refinery's cobalt capacity to 1,100 t/yr were delayed until late 2003 or 2004. Cobalt output was forecast to steadily increase as the plant was expanded (Metal Bulletin, 2001h; Ryan's Notes, 2001; American Metal Market, 2002).

Canada.—Falconbridge Ltd. produced 630 t of cobalt in concentrate from its Sudbury, Ontario, mines and 318 t of cobalt in concentrate from its Raglan Mine in Quebec. Nickel-copper matte produced at the Sudbury smelter was refined at the company's Nikkelverk refinery in Norway. In 2001, this matte contained 1,788 t of cobalt; 56% of the cobalt originated from ores produced at company mines, and 44% from custom feed materials, defined as feeds that did not originate from Falconbridge mines. The custom feed was primarily nickel-copper-cobalt secondary materials, plus some intermediate feedstocks and smaller amounts of concentrates. Falconbridge's Sudbury mine and smelter production levels in 2000 and 2001 were lower than those of prior years because of a strike by production and maintenance workers that began on August 1, 2000, and extended until February 20, 2001. During the strike, the mines and smelter at Sudbury were operated by staff employees at reduced rates. The mines at Sudbury returned to full production rates in June (Falconbridge Ltd., 2002b, p. 20; 2002c, p. 10-13, 16).

Inco Ltd. produced cobalt oxide at its Thompson, Manitoba, refinery and cobalt cathode at its Port Colborne, Ontario, refinery from feed materials originating primarily from nickel mines in Thompson and Sudbury, respectively. In 2001, Inco produced 1,450 t of cobalt in Canada from both operations, approximately the same as the 1,470 t produced in 2000 (Cobalt Development Institute, 2002b).

In June, Inco and the Government of Newfoundland and Labrador resumed formal negotiations on the terms of the commercial development of the Voisey's Bay nickel-copper-cobalt-sulfide deposit in northeastern Labrador. At yearend, the principal issues to be resolved included the terms of the movement of concentrates produced by the project to Inco's existing Canadian operations as part of the financing of the project, the scope of the guarantee covering processing in the Province required by the Provincial Government, the Government's financial participation, and flexibility in the timing of the project's development and financing arrangements. In addition, before commercial development could proceed, Inco would need to reach impact and benefits agreements with the Labrador Inuit Association and Innu Nation, land claims negotiations between the Federal and

Provincial Governments and aboriginal groups would have to be completed to Inco's satisfaction, and permitting and design and engineering parameters for the project would need to be completed. In September, Inco announced that it had completed the exploration program for the Voisey's Bay deposit and other claim areas in Labrador. The company reported that the exploration program had delineated 31 Mt of proven mineral reserves and that the current reserves and resources would be sufficient to support a mine and mill on the scale contemplated for the project (Inco Ltd., 2001; 2002, p. 5, 9, 43).

The Sherritt International Corp.-General Nickel Co. S.A. joint venture's refinery in Fort Saskatchewan, Alberta, produced a record 2,943 t of cobalt in 2001, a 3% increase from the 2,855 t of cobalt in 2000. The increase in production was attributed to modifications to the leach autoclave configuration and continued operating stability of the refinery (Sherritt International Corp., 2002, p. 5-6). Most of the feed was in the form of nickel-cobalt mixed sulfides from the joint venture's operations at Moa Bay, Cuba. As a result of a U.S. embargo on imports of products originating from Cuba, nickel and cobalt produced by Sherritt cannot be sold to U.S. customers.

Canmine Resources Corp. worked on modifying and the initial commissioning of its hydrometallurgical refinery in Cobalt, Ontario. The company expected the retrofitting to be completed during the first quarter of 2002 and commissioning to be completed in late April, after which production would be ramped up to the initial full capacity of 300 t/yr of cobalt in carbonates, sulfates, or oxides. Initial feedstock for the refinery will come from a stockpile of cobalt-silver bearing materials purchased from Agnico-Eagle Mines Ltd. in early 2000 and from recycling brokers and other parties in the United States and Europe. Canmine planned to expand the refinery's capacity to 1,000 t/yr or more of cobalt, depending in part on the development of the company's Werner Lake cobalt project and Maskwa nickel project in southwestern Ontario-southeastern Manitoba (Canmine Resources Corp., 2001; 2002a; 2002b, p. 2).

China.—An estimated 1,470 t of refined cobalt metal, metal powders, and compounds was produced in China from domestic and imported raw materials, a 23% increase from the 1,200 t estimated for 2000 (Cobalt Development Institute, 2002b). The number of Chinese cobalt refiners and processors was reported to be approximately 50. The largest refiners were Jinchuan Non-Ferrous Metals Corp. and Ganzhou Cobalt & Tungsten Co., Ltd. Jinchuan produced cobalt cathode and other cobalt products from domestic nickel-copper-cobalt sulfide ores mined and refined at Jinchuan, Gansu Province. Jinchuan planned to double the cobalt capacity of its refinery to 1,000 t in 2001, and then double it again to 2,000 t by 2005. According to reports, Jinchuan investigated sourcing nickel-cobalt feed materials from the Nonoc nickel-cobalt laterite project in the Philippines and the Mt. Margaret laterite project in Australia. Late in the year, Jinchuan reportedly signed an agreement with Empresa Cubana Exportadora de Minerales y Metales (also known as Cubaniquel) to purchase 300 t/yr of cobalt "concentrate" from Cuba (China Metal Market, 2001a, p. 13-14; 2001b, p. 12-13; Metal Bulletin, 2001c; Song, 2001, p. 3-16; Aidong, 2002).

Ganzhou, which produced cobalt metal powders and compounds at Ganzhou, Jiangxi Province, and several of the smaller refiners, also planned to expand their cobalt refining

capacities in the near term. To lessen their dependence on imported raw materials, an increasing number of these smaller refiners worked on developing local cobalt resources (Song, 2001, p. 3-16; Aidong, 2002).

During the year, Umicore commissioned a cobalt refinery in south central China. The refinery had the capacity to produce 2,000 t/yr of cobalt from low-grade primary and secondary materials. Some of the cobalt from the new refinery would be processed into cobalt metal powders at Umicore's metal powder plant in Shanghai. Umicore also planned to produce cobalt compounds for sale in China and for export to other markets (Gellens, 2002, p. 7-8).

Congo (Kinshasa).—In March, La Générale des Carrières et des Mines (Gécamines) finalized an agreement with the Kababankola Mining Co. (KMC) for the treatment of cobalt-copper concentrates produced from Gécamines' Central Group. The mines and concentrator covered by the agreement would be effectively leased to KMC. The concentrates would be toll-refined at the Shituru refinery in Likasi, which would remain under Gécamines' control. KMC is a joint-venture company created by Gécamines and Tremalt Ltd., a private company based in the British Virgin Islands, which is owned by a Zimbabwean businessperson (Metal Bulletin, 2001b; Reuters 2001b; The Financial Gazette, 2001§).

Gécamines and L'Enterprise Generale Malta Forrest S.P.R.L. produced copper-cobalt concentrates from the Luiswishi Mine. OMG had a long-term supply contract for approximately 4,500 t/yr of cobalt in concentrates from Luiswishi for its Kokkola refinery in Finland (OM Group, Inc., 2002, p. 14).

The Big Hill smelter at Lubumbashi, which became operational in late 2000, was running routinely by the fourth quarter of 2001. The smelter, operated by Le Société pour le Traitement de la Terril de Lubumbashi (a joint venture between Gécamines, OMG, and S.A. Groupe George Forrest), produced a cobalt-copper alloy from stockpiled slag, which was shipped to OMG's Kokkola refinery. The stockpile was expected to supply the smelter for 20 years at a production rate of 5,000 t/yr of contained cobalt (OM Group, Inc., 2002, p. 10, 14).

In June, Gold City Industries Ltd. of Vancouver, British Columbia, signed a memorandum of understanding with Congo Stars Mining SARL (Cosamin) and a Vancouver businessperson to bring the Congo Stars copper-cobalt mine near Lubumbashi back into production. In September, the parties signed the Costamin International Joint Venture agreement, under which Gold City and the businessperson could each earn a 25% interest in the joint venture by investing to develop mining and other business opportunities in Congo (Kinshasa). The joint venture had a presidential decree and export permit that allowed it to direct ship cobalt-copper oxides from the Etoile concession, which contained the Congo Stars Mine; the Kansuki concession, east of Kolwezi; and other mining concessions. By yearend, artisan miners had been contracted to selectively mine high-grade oxides (heterogenite) for direct shipment to processing plants and other buyers in South Africa and elsewhere. In addition, the joint venture planned to study the feasibility of constructing a processing plant in Congo (Kinshasa) (Gold City Industries Ltd., 2001a, b; 2002, p. 6).

Congo Mineral Development Ltd. (CMD) (a joint venture between America Mineral Fields Inc. and Anglo American plc) renegotiated the commercial terms for the development of the

Kolwezi tailings project with Gécamines. Initial production from the project was to be 42,000 t/yr of copper and 7,000 t/yr of cobalt cathode from stockpiled tailings. In September, CMD completed a pilot-plant program in Johannesburg, South Africa, which established a metallurgical flowsheet using solvent extraction-electrowinning to treat Kolwezi tailings. A full feasibility study on the project was to begin after CMD obtained unequivocal title to the project. The necessary approvals from the Government of Congo (Kinshasa) had not been received by yearend (America Mineral Fields Inc., 2002, p. 2-5).

Tenke Mining Corp. worked with BHP Billiton to prepare technical and economic studies on the development of copper-cobalt deposits at Tenke and Fungurume on a smaller scale than the 100,000 t/yr of copper and 8,000 t/yr of cobalt originally planned in the base case study of the deposits. In May, Tenke Mining Corp. announced that Phelps Dodge Corp. had joined BHP World Exploration Inc. (BHP) in its option agreement for the proposed development of the Tenke-Fungurume deposits. BHP (which became a part of BHP Billiton) held an option to acquire a controlling interest in and to act as the primary operator of the project. Under its agreement with BHP, Phelps Dodge could earn up to 50% of BHP's position in the project. Significant activity on the project continued to be delayed by the poor investment climate resulting from the ongoing civil war in Congo (Kinshasa), however, and Tenke Mining remained under force majeure (Tenke Mining Corp., 2001; 2002, p. 2-3, 7).

La Société Minière de Kabolela et Kipese (SMKK) was a joint venture created by Melkior Resources Inc. (60%) and Gécamines (40%) to mine the Kabolela copper-cobalt and Kipese cobalt-gold-platinum deposits near the city of Likasi. As of the end of Melkior's fiscal year (August 30, 2001), SMKK had not yet begun commercial production. Owing to limited capital resources, Melkior decided to restrict expenditures on its Congo (Kinshasa) interests and to shift its focus towards projects in Quebec, Canada (Melkior Resources Inc., 2001).

Kumba Resources Ltd. was formed in November from the mining assets unbundled from Iscor Ltd. Iscor's option to rehabilitate Gécamines' Kamoto copper-cobalt mine was transferred to Kumba (Kumba Resources Ltd., undated§).

Cuba.—Moa Nickel S.A., which was part of the joint venture between Sherritt and General Nickel, mined nickel-cobalt laterites at Moa Bay and produced mixed sulfides containing 32,360 t of nickel and cobalt, a 10% increase from the 29,520 t produced in 2000. The increase in production was attributed to steady plant operation, a higher ore grade, and systematic debottlenecking initiatives (Sherritt International Corp., 2002, p. 5-6). The mixed sulfides produced at Moa were sent to the joint venture's refinery in Fort Saskatchewan, Alberta, Canada. Nickel and cobalt of Cuban origin cannot be imported into the United States because of a U.S. embargo on imports from Cuba.

Finland.—OMG produced 8,100 t of cobalt in cobalt metal powders, briquettes, oxides, and compounds, 5% more than the 7,700 t produced in 2000 (Cobalt Development Institute, 2002b). In 2001, the company's Kokkola Chemicals Oy refinery began processing iron-copper-cobalt alloy from its Big Hill smelter in Congo (Kinshasa). The refinery also processed cobalt-bearing materials from Australia, the Luiswishi Mine in Congo (Kinshasa), Russia, the United States, and Zambia (Platts

Metals Week, 2001b; OM Group, Inc., 2002, p. 14).

France.—The Eramet Group produced cobalt chloride at its refinery at Sandouville, near Le Havre. Feed for the refinery was nickel matte imported from Eramet subsidiary Le Nickel-SLN's Doniambo smelter in New Caledonia.

India.—Three companies refined cobalt from imported raw materials. Nicomet Industries Ltd. produced cobalt cathode and various compounds at its plant in Cuncolim, Goa State; Rubamin Ltd. produced cobalt cathode and various compounds at its plant in Vadodara, Gujarat State; and Conic Metals Ltd. produced cobalt sulfate and carbonate at its plant in Mumbai, Maharashtra State. In addition to this refinery production, cobalt metal powder was recovered from cemented carbide scrap by Sandvik Asia Ltd. at a pilot plant in Pune, Maharashtra State, and spent catalysts from plants producing terephthalic acid, dimethyl terephthalate, and OXO alcohols were reprocessed by more than a dozen small cobalt chemical processors (Cobalt Development Institute, 2001).

Indonesia.—State-owned P.T. Aneka Tambang (Antam) exported lateritic nickel-cobalt ore to QNI's Yabulu refinery in Queensland, Australia. Several companies, including QNI, worked on projects to explore and develop Indonesia's nickel-cobalt laterite resources.

In June, Weda Bay Minerals Inc. completed a prefeasibility study on a project that would use pressure acid leaching to recover nickel and cobalt from laterite deposits on Halmahera Island. Weda Bay Minerals and 19.9% shareholder OMG determined that additional resource drilling, detailed metallurgical testwork, and infrastructure studies were necessary before deciding on the size of the project and starting a bankable feasibility study. In late July, the project was placed on care and maintenance because of OMG's concerns that business uncertainty in Indonesia at that time would make it difficult to raise project financing on acceptable terms. Weda Bay Minerals continued with metallurgical testwork and completed two revised prefeasibility studies—one with lower total capital costs and another with lower operating costs (Weda Bay Minerals Inc., 2001a, b, c).

Late in the year, Falconbridge withdrew from the Gag Island nickel-cobalt laterite project. The tentative agreement that Falconbridge had established in June 2000 to form a joint venture with BHP Billiton was conditional upon several matters, including the resolution of an issue related to open pit mining in areas designated as protected forest. Falconbridge allowed its agreement with BHP Billiton to terminate after extensive deliberations with the Government did not resolve this issue. At yearend, the joint venture between BHP Billiton and Antam was seeking a suspension of the Gag Island contract of work and was reviewing its options for the project (BHP Billiton, 2002b; Falconbridge Ltd., 2002b, p. 3).

Japan.—Sumitomo Metal Mining Co., Ltd., produced electrolytic cobalt, cobalt oxide, and cobalt compounds as a byproduct of nickel at its Niihama nickel refinery in Ehime Prefecture. In July, Sumitomo announced that it had decided to build a plant in the Philippines that would use pressure acid leaching technology to process lateritic ores (also discussed under the Philippines section below). The mixed sulfide produced at the new plant, containing approximately 700 t of cobalt, would be refined at Niihama.

Morocco.—Cie. de Tifnout Tiranimine (CTT) mined cobalt

arsenic deposits at Bou Azzer and produced concentrates. CTT refined the concentrates and tailings generated by past mining at Bou Azzer to produce 1,200 t of cobalt cathode, the same amount as that produced in 2000 (Cie. de Tifnout Tiranimine, 2001; Cobalt Development Institute, 2002b).

New Caledonia.—Lateritic nickel-cobalt ore was exported to QNI's Yabulu refinery for processing. Nickel matte from Le Nickel-SLN's Doniambo smelter was sent to Eramet's refinery in Sandouville, France, where it was refined into nickel cathode, nickel chloride, and cobalt chloride.

Inco continued to test its proprietary pressure acid leaching-solvent extraction process on a variety of lateritic ores at its Goro pilot plant in southern New Caledonia. In April, after completing a bankable feasibility study, Inco announced that it planned to proceed with the construction of a fully integrated mining and processing operation to produce nickel and cobalt at Goro. The commercial facility would have an annual capacity of 54,000 t/yr of nickel as oxide and 5,400 t/yr of cobalt as carbonate. Inco anticipated that construction would be completed and production would begin in late 2004. Inco held an 85% interest in the Goro project and Bureau de Recherches Géologiques et Minières, a French Government agency, held the remaining 15%. During the year, Inco held discussions with a number of companies interested in acquiring a minority interest in the project, including Eramet (Inco Ltd., 2002, p. 4, 9, 11, 42; Reuters Ltd., 2001c).

Argosy Minerals Inc. signed an agreement with Russia's Open Joint Stock Company MMC Norilsk Nickel and New Caledonia's Société des Mines de la Tontouta (SMT) for the development of the Nakety nickel-cobalt laterite deposits on the east coast of New Caledonia. Under the terms of the agreement, Norilsk Nickel could earn up to a 90% interest in the Nakety project by completing a bankable feasibility study within 2 years and making a series of scheduled payments to Argosy. SMT would retain the remaining 10% interest in the project (Argosy Minerals Inc., 2002).

Norway.—In 2001, Falconbridge produced 3,314 t of cobalt at its Nikkelverk refinery, a 3% decrease from the 3,431 t produced in 2000. During 2001, 28% of the cobalt produced at Nikkelverk originated from Falconbridge mines in Canada and 72% originated from custom feeds, defined as feeds that did not originate at Falconbridge mines. The custom feeds included matte from BCL Ltd. in Botswana, scrap, and intermediate materials (Falconbridge Ltd., 2002a, p. 20; 2002c, p. 15-16).

Papua New Guinea.—Highlands Pacific Ltd. and Orogen Minerals Ltd. held discussions with potential joint-venture partners on the Ramu nickel-cobalt laterite project. On the basis of a feasibility study completed in 1998, the project was to use pressure acid leaching technology to produce 33,000 t/yr of nickel metal and 3,200 t/yr of cobalt as cobalt sulfate. During the fourth quarter, a major international group undertook due diligence on the project (Highlands Pacific Ltd., 2001, p. 1; 2002, p. 1).

Philippines.—Lateritic nickel-cobalt ore from the Philippines was exported to QNI's Yabulu refinery for processing.

In July, Sumitomo announced that it had decided to build a plant that would use pressure acid leaching technology to process low-grade lateritic ores stockpiled at the Rio Tuba nickel mine on Palawan Island. The plant, which would be built

adjacent to the mine, would produce a mixed nickel-cobalt sulfide intermediate product, which would be refined at Sumitomo's Niihama Nickel Refinery in Japan. Enough stockpiled ore was available to produce mixed sulfide containing 10,000 t/yr of nickel and 700 t/yr of cobalt for approximately 20 years. During the year, Sumitomo discussed the establishment of a joint-venture company to advance the project with three companies that collaborated with Sumitomo on the feasibility studies—Rio Tuba Nickel Mining Corp., Nissho Iwai Corp., and Mitsui & Co., Ltd. Production was scheduled to begin in 2004, subject to environmental and other approvals (Sumitomo Metal Mining Co., Ltd., 2001).

Impala Platinum Holdings Ltd. (Implats) of South Africa completed a feasibility study on the Nonoc nickel-cobalt laterite project as part of a memorandum of understanding signed with Philnico Developments Ltd. in 2000. By midyear, Implats had decided to postpone further involvement in the project until Philnico was able to bring in a major nickel partner and additional funding. Plans by Chinese nickel-cobalt producer Jinchuan to invest in the project were reportedly delayed by the unstable political situation in the Philippines (Metal Bulletin, 2001c; Impala Platinum Holdings Ltd., 2001, p. 43, 69; Jinchuan Nonferrous Metals Corp., 2001§).

Russia.—Nickel and cobalt production in Russia involved a complex flow of ores, flotation concentrates, precipitates, and mattes between various production sites. The main feed materials were domestic nickel-copper sulfide and nickel-cobalt laterite ores and imported nickel- and cobalt-bearing secondary materials. Russia had the capacity to produce refined cobalt at four locations—Open Joint Stock Company MMC Norilsk Nickel refineries at Monchegorsk on the Kola Peninsula and Norilsk in Siberia, the Ufaleynickel Joint Stock Co. refinery at Verkhniy Ufaley in the Ural Mountains, and the Yuzhuralnickel Joint Stock Co. refinery at Orsk, also in the Ural Mountains (Roskill Information Services Ltd., 1995, p. 11-15).

Total Russian cobalt production was 15% higher than that of 2000 (Interfax Mining & Metals Report, 2002). Ninety-five percent of this production was by Norilsk Nickel. Norilsk Nickel reported the physical volume of its cobalt production for the years 1996 through 2001 as a percentage of its production in 1996. In 2001, Norilsk Nickel's cobalt production increased by 4.1% from that of 2000. The cobalt from Norilsk Nickel's Siberian operations was 89.8% ingots, 5.9% cobalt in hydroxide, and 4.3% cobalt in sulfate. The cobalt from Norilsk Nickel's operations on the Kola Peninsula was 2.8% carbonyl cobalt and 97.2% cobalt in concentrate, which was toll-refined by Ufaleynickel (OJSC MMC Norilsk Nickel, 2002, p. 4, 8, 36, 40). In August, Norilsk Nickel signed an agreement with Argosy Minerals for the development of the Nakety laterite deposits (covered under the New Caledonia section above).

In 2001, management of the Yuzhuralnickel refinery was taken over by Chelyabinsk Metallurgical Works (Mechel). The new management reportedly decided not to pursue prior plans to make cobalt products. Instead, the company sent cobalt concentrates to Ufaleynickel to be refined (Metal Bulletin, 2001e, i).

South Africa.—Cobalt was mined as a byproduct from six platinum-group metal mines and as a coproduct from one nickel mine (Harding, 2001). Two South African companies produced

refined cobalt as a byproduct of domestic platinum mining and refining. Rustenburg Base Metal Refiners Pty. Ltd. (a subsidiary of Anglo American plc) produced cobalt sulfate at its refinery near Rustenburg, Northwest Province. Impala Platinum Ltd. (a subsidiary of Implats) produced cobalt metal powder at its base-metals refinery near Springs, Gauteng Province. Implats was considering expanding the capacity of the Springs refinery to 60,000 t/yr of nickel and 4,200 t/yr of cobalt to accommodate an increase in feed that would result from the development of the Nonoc project in the Philippines (covered under the Philippines section above).

The Nkomati nickel sulfide mine in Mpumalanga Province was a joint venture between Anglovaal Mining Ltd. (Avmin) and Anglo American plc. In recent years, the cobalt content of concentrates produced from Nkomati has been approximately 210 to 230 t/yr. In 2001, a feasibility study on expanding production from the mine neared completion. The study included the construction of a new concentrator and a processing plant, which would use the "Activox" low-pressure leach process. Production rates following expansion were estimated at 17,500 t/yr of nickel cathode, 9,000 t/yr of copper cathode, 800 t/yr of cobalt as carbonate, and 80,000 ounces of platinum group metals in concentrates (Anglovaal Mining Ltd., 2000, 2002a§, b§).

Umicore South Africa Pty. (a subsidiary of Umicore) produced cobalt compounds from low-grade cobalt-containing residues in Roodepoort, near Johannesburg. International Metal Processing (Pty.) Ltd. worked on a 3-year redevelopment and extension program to enhance its cobalt-copper-nickel refinery in Brakpan, Gauteng Province. At the refinery, mineral concentrates were processed to produce cobalt cathode, metal powder, oxides, and compounds.

Uganda.—Banff Resources Ltd. of Vancouver focused its efforts on improving the operations of the Kasese cobalt refinery in southwestern Uganda. The refinery was designed to recover cobalt from stockpiled pyrite concentrates by using bacterial leaching followed by solvent extraction-electrowinning. Because of operational problems, commissioning of the refinery extended into 2001. For accounting purposes, Banff declared that the refinery had commenced commercial production effective July 1, 2001, even though it had not achieved production at 60% of design capacity for a continuous 3-month period. In 2001, Kasese produced 634 t of cobalt cathode as compared with 420 t produced in 2000. The refinery continued to experience operational problems, however, and throughput and production rates remained significantly below the engineered design capacity of 1,000 t/yr of cobalt. In August, Banff's parent company, Normandy Mining Ltd., announced its intention to sell its interest in the Kasese project. At yearend, Banff stated that its continuation as a going concern was dependent upon a number of factors. These included achieving a higher production rate at Kasese, realizing improved operating efficiencies and reduced operating costs, a cobalt metal settlement price above yearend 2001 prices, political stability in the region, and receiving continuing financial support from its parent company (Banff Resources Ltd., 2001a; 2001b, p. 5; Normandy Mining Ltd., 2001; Cobalt Development Institute, 2002b).

Zambia.—Mopani Copper Mines Plc [owned by Glencore

International AG (46%), First Quantum (44%), and Zambia Consolidated Copper Mines Ltd. (ZCCM) (10%)] produced 1,876 t of cobalt metal at its Nkana cobalt refinery, an 83% increase from the 1,026 t produced in 2000 (Cobalt Development Institute, 2002b). The refinery processed concentrates from Mopani's Nkana Mine, Crew Development Corp.'s Chibuluma West Mine, and Konkola Copper Mines PLC operations. Towards the end of the year, shareholder First Quantum began a critical assessment of its operations and considered initiatives to reduce unit costs and contain capital expenditures at the Mopani operations in an effort to reduce operating losses at current (October 2001) cobalt and copper prices (First Quantum Minerals Ltd., 2001; Metal Bulletin, 2001d).

Konkola Copper Mines PLC (KCM) produced 3,272 t of cobalt in concentrates from newly mined and stockpiled ores from the Nchanga Open Pit. The concentrates yielded 2,422 t of finished cobalt, which was toll-refined at the Chambishi and Nkana refineries. During the year, KCM continued to refurbish its assets and completed a feasibility study on the Konkola Deep mining project. In October, KCM informed the Government of the Republic of Zambia and its shareholders [Zambia Copper Investments Ltd. (a subsidiary of Anglo American), 65%; ZCCM Investments Holdings PLC, 20%; CDC Group plc, 7.5%; and the International Finance Corp., 7.5%] that as a result of the poor outlook for copper and cobalt prices and its inability to raise project financing, it had decided to delay the start of the Konkola Deep project. In January 2002, Anglo American announced that without the prospect of being able to develop the Konkola Deep project, it could not justify further investment in KCM beyond that committed at the time of acquisition. KCM's existing operations were high cost and have a relatively short life; developing the Konkola Deep project was the main reason for acquiring KCM. A shareholders steering committee was formed to evaluate options for KCM. Anglo American forecast that unless substantial additional financing became available, or the assets were sold or transferred on a going concern basis, operations would cease in approximately 1 year (Metal Bulletin, 2001d; Anglo American plc, 2002; Zambia Copper Investments Ltd., 2002, p. 1-8).

Chambishi Metals plc (a subsidiary of Avmin) produced 2,789 t of cobalt metal at its Chambishi cobalt refinery, a 20% increase from the 2,316 t produced in 2000. The refinery processed concentrates from Mopani's Nkana Mine, Konkola Copper Mines PLC operations, and unnamed sources in Congo (Kinshasa). In early 2001, Chambishi began processing slag in its new smelter and matte leach facility. The facility, which was named COSAC for "cobalt from slag and copper as a byproduct," was designed to recover cobalt and copper from slag stockpiled at Nkana. COSAC's furnace was shut down in May for inspection and repairs following a water pipe leak and again later in the year for additional repairs. At yearend, the facility was operating at 50% of capacity. Full production from COSAC was expected to be 4,200 t/yr of cobalt and approximately 3,500 t/yr of copper. Leach liquor from COSAC was sent to the recently upgraded and expanded Chambishi refinery for treatment. After the COSAC plant and expanded refinery were fully operational, total production from Chambishi was forecast at 6,000 t/yr of cobalt and more than

10,000 t/yr of copper (Anglovaal Mining Ltd., 2001a, b, 2002; Metal Bulletin, 2001a, d; Cobalt Development Institute, 2002b; Chambishi Metals plc, undated§).

In late 2000, Roan Antelope Mining Corp. was put under receivership because of unpaid debts. The company's assets, including the Baluba and Luanshya mines, the Muliashi deposit, and approximately 10 Mt of smelter slag, were put up for sale. Mining operations were suspended in February 2001 as a result of flooding following heavy rains. The assets had not been sold by yearend (Metal Bulletin, 2001g; Platts Metals Week, 2001c; Reuters Ltd., 2001a).

Copper-cobalt ore from the Chibuluma West Mine was sent to Mopani's Nkana operations to be concentrated and refined. The Chibuluma operations are 85% owned by Metorex Ltd. (a subsidiary of Crew Development Corp.) and 15% owned by ZCCM (Crew Development Corp., undated§).

Orion Mining and Exploration Ltd. processed slag imported from Congo (Kinshasa) at its plant in Kabwe and exported the resulting cobalt alloy to China and Europe. In early 2002, Orion announced that the plant had been forced to close because of falling prices for cobalt and copper. The company was considering converting the plant to process tin concentrates (Platt's Metals Week, 2000; The Times of Zambia—Ndola, 2002§).

Outlook

World production of refined cobalt has steadily increased since 1993. In addition to production, inventory releases and recycled cobalt have contributed to supply. Between 1993 and 2000, world demand for cobalt also increased. Strong demand for cobalt to make rechargeable batteries and growth in cobalt consumption in Asia resulted in total annual growth rates for cobalt demand that were above the average annual growth rates for the metals industry as a whole (Searle, 2002). In spite of this growth in demand, the general trend in cobalt prices has been downward since 1995, because supply was growing at a faster rate than demand.

In 2001, world demand for cobalt fell because of poor global economic conditions; a worldwide downturn in the cellular telephone market, which impacted the demand for cobalt in rechargeable batteries; and reduced demand from the electronics sector, which, like the battery sector, was drawing down excess inventories. In addition, the terrorist attacks on September 11 in the United States were expected to have a negative impact on future cobalt demand from the superalloy sector. However, overall demand is expected to increase once general economic conditions improve (Cobalt Development Institute, 2002a; Falconbridge Ltd., 2002a, p. 32; n.v. Umicore s.a., 2002, p. 20; Searle, 2002). In the long term, if cobalt supply continues to increase at a faster rate than the market can absorb, downward pressure on cobalt prices will continue. If prices drop below production costs for an extended period of time, supplies from unprofitable operations are likely to be curtailed. The cost at which cobalt production is marginally profitable has been estimated in the \$6 to \$8 per pound range (Searle, 2001, 2002; Southwood and Gray, 2001).

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TABLE 1
SALIENT COBALT STATISTICS 1/

(Metric tons, cobalt content, unless otherwise specified)

	1997	1998	1999	2000	2001
United States:					
Consumption:					
Reported	9,160 r/	9,380 r/	8,660 r/	8,980 r/	9,490
Apparent	11,200	11,500	10,700	11,600 r/	11,800
Imports for consumption	8,430	7,670	8,150	8,770	9,410
Exports	1,570	1,680	1,550	2,630	3,210
Stocks, December 31:					
Industry 2/	763	751	738	820 r/	851
U.S. Government 3/	17,100	14,700	13,200	10,200	7,200 e/
Price, metal, per pound 4/	\$23.34	\$21.43	\$17.02	\$15.16	\$10.55
World Production:					
Mine	27,400 r/	34,900 r/	31,000 r/	33,800 r/	36,700 e/
Refinery	27,100	30,900	32,400	35,200	38,400 e/

e/ Estimated. r/ Revised.

1/ Data are rounded to no more than three significant digits, except prices.

2/ Stocks held by cobalt processors and consumers.

3/ Defense National Stockpile Center. Includes material committed for sale pending shipment.

4/ Annual average U.S. spot price for minimum 99.8% cobalt cathode reported by Platts Metals Week.

TABLE 2
U.S. GOVERNMENT NATIONAL DEFENSE STOCKPILE
SALES AND SHIPMENTS 1/

(Metric tons, cobalt content)

	2000	2001
Sales:		
Fiscal year 2/	2,720	2,210
Calendar year	3,080	1,770
Shipments: 3/		
Fiscal year 2/	2,150	2,930
Calendar year	2,960	3,050 e/

e/ Estimated.

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

2/ Twelve-month period ending September 30 of year stated.

3/ Calculated from year end inventory levels.

Source: Defense National Stockpile Center.

TABLE 3
U.S. REPORTED CONSUMPTION AND STOCKS OF COBALT 1/ 2/

(Metric tons, cobalt content)

	2000	2001
Consumption by end use:		
Steels	230 r/	624 3/
Superalloys	4,070 r/	4,850
Alloys (excludes steels and superalloys):		
Magnetic alloys	625 r/	472
Other alloys 4/	867 r/	661 3/
Cemented carbides 5/	760	720
Chemical and ceramic uses	2,360	2,100
Miscellaneous and unspecified	63	63
Total	8,980 r/	9,490
Consumption by form:		
Chemical compounds (organic and inorganic) 6/	1,840	1,510
Metal	4,590 r/	5,240
Purchased scrap	2,550	2,740
Total	8,980 r/	9,490
Stocks, December 31: 7/		
Chemical compounds (organic and inorganic) 6/	252	242
Metal	410 r/	427
Purchased scrap	159	181
Total	820 r/	851

r/ Revised.

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

2/ Includes estimates.

3/ Data are not comparable to those for 2000 because of a change in reporting.

4/ Includes nonferrous alloys, welding materials, and wear-resistant alloys.

5/ Includes diamond tool matrices, cemented and sintered carbides, and cast carbide dies or parts.

6/ Includes oxides.

7/ Stocks held by cobalt processors and consumers.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM 1/

(Metric tons unless otherwise specified)

	2000	2001
Metal: 2/		
Gross weight	7,210	7,910
Cobalt content 3/	7,210	7,910
Value thousands	\$213,000	\$183,000
Oxides and hydroxides:		
Gross weight	1,540	1,280
Cobalt content 3/	1,110	921
Value thousands	\$37,100	\$25,700
Other forms:		
Acetates:		
Gross weight	183	398
Cobalt content 3/	44	95
Value thousands	\$1,290	\$2,410
Carbonates:		
Gross weight	5	49
Cobalt content 3/	2	23
Value thousands	\$103	\$649
Chlorides:		
Gross weight	33	53
Cobalt content 3/	8	13
Value thousands	\$295	\$419
Sulfates:		
Gross weight	1,490	1,650
Cobalt content 3/	402	445
Value thousands	\$9,340	\$7,500
Total:		
Gross weight	10,500	11,300
Cobalt content 3/	8,770	9,410
Value thousands	\$261,000	\$219,000

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

2/ Unwrought cobalt, excluding alloys and waste and scrap.

3/ Estimated from gross weights.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY 1/

Country of origin	Metal 2/			Oxides and hydroxides			Other forms 3/			Total		
	Gross weight (metric tons)	Cobalt content 4/ (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content 4/ (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content 4/ (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content 4/ (metric tons)	Value (thousands)
2000:												
Australia	288	288	\$7,370	2	1	\$53	(5/)	(5/)	\$3	290	290	\$7,430
Belgium	118	118	4,820	411	296	11,300	2	1	25	531	415	16,100
Brazil	340	340	9,380	--	--	--	--	--	--	340	340	9,380
Canada	809	809	24,900	1	1	57	4	2	70	815	812	25,000
China	12	12	474	15	11	363	4	1	34	31	24	871
Congo												
(Kinshasa)	893	893	22,200	--	--	--	--	--	--	893	893	22,200
Finland	1,290	1,290	41,400	900	648	19,400	1,630	436	10,300	3,820	2,380	71,100
France	43	43	3,250	42	30	2,000	--	--	--	85	73	5,250
Germany	75	75	3,040	5	4	100	(5/)	(5/)	14	80	79	3,150
Japan	82	82	3,850	2	2	44	(5/)	(5/)	8	85	84	3,910
Morocco	62	62	1,570	--	--	--	--	--	--	62	62	1,570
Netherlands	10	10	284	--	--	--	--	--	--	10	10	284
Norway	1,470	1,470	42,900	--	--	--	--	--	--	1,470	1,470	42,900
Russia	1,100	1,100	32,100	--	--	--	11	3	100	1,110	1,100	32,200
South Africa	243	243	5,730	21	15	468	--	--	--	264	258	6,200
Uganda	41	41	1,220	--	--	--	--	--	--	41	41	1,220
United Kingdom												
Kingdom	10	10	311	136	98	3,320	52	12	399	198	120	4,030
Zambia	318	318	7,510	--	--	--	--	--	--	318	318	7,510
Other	11	11	329	--	--	--	6	2	63	17	12	392
Total	7,210	7,210	213,000	1,540	1,110	37,100	1,710	457	11,000	10,500	8,770	261,000
2001:												
Australia	168	168	3,240	--	--	--	--	--	--	168	168	3,240
Belgium	256	256	7,870	406	292	9,480	9	3	79	671	551	17,400
Brazil	286	286	6,270	--	--	--	(5/)	(5/)	5	286	286	6,270
Canada	818	818	21,900	--	--	--	--	--	--	818	818	21,900
China	62	62	981	1	1	24	17	4	125	80	67	1,130
Congo												
(Kinshasa)	682	682	13,500	--	--	--	--	--	--	682	682	13,500
Finland	1,040	1,040	27,200	721	519	12,200	1,940	523	9,490	3,700	2,080	48,900
France	8	8	484	45	32	1,800	--	--	--	52	40	2,290
Germany	30	30	1,200	9	6	226	--	--	--	39	36	1,430
Japan	34	34	1,130	1	1	77	8	2	102	43	36	1,310
Morocco	210	210	4,570	--	--	--	1	(5/)	6	211	210	4,580
Norway	1,440	1,440	29,700	--	--	--	--	--	--	1,440	1,440	29,700
Russia	1,610	1,610	38,500	--	--	--	--	--	--	1,610	1,610	38,500
South Africa	661	661	13,300	--	--	--	--	--	--	661	661	13,300
Uganda	60	60	1,370	--	--	--	--	--	--	60	60	1,370
United Kingdom												
Kingdom	45	45	687	88	64	1,930	139	34	911	272	142	3,520
Zambia	497	497	10,500	--	--	--	--	--	--	497	497	10,500
Other	5	5	168	9	6	31	35	10	268	49	22	466
Total	7,910	7,910	183,000	1,280	921	25,700	2,150	577	11,000	11,300	9,410	219,000

-- Zero.

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

2/ Unwrought cobalt, excluding alloys and waste and scrap.

3/ Includes cobalt acetates, cobalt carbonates, cobalt chlorides, and cobalt sulfates.

4/ Estimated from gross weights.

5/ Less than 1/2 unit.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 6
U.S. EXPORTS OF COBALT IN 2001, BY COUNTRY 1/ 2/

Country of destination	Metal 3/		Oxides and hydroxides		Acetates		Chlorides		Total	
	Gross weight (metric tons)	Value 4/ (thou-sands)	Gross weight (metric tons)	Value 4/ (thou-sands)	Gross weight (metric tons)	Value 4/ (thou-sands)	Gross weight (metric tons)	Value 4/ (thou-sands)	Cobalt content 5/ (metric tons)	Value 4/ (thou-sands)
Argentina	8	\$271	24	\$380	--	--	--	--	25	\$651
Belgium	1,210	30,600	12	608	7	\$74	--	--	1,220	31,200
Brazil	22	491	12	172	35	277	--	--	39	939
Canada	112	2,880	40	911	26	195	44	\$453	157	4,430
Colombia	11	204	16	330	2	21	--	--	23	555
France	191	4,460	1	36	--	--	--	--	191	4,500
Germany	117	3,190	40	148	--	--	--	--	146	3,340
Ireland	44	1,130	--	--	--	--	--	--	44	1,130
Japan	148	4,290	11	216	--	--	--	--	155	4,500
Korea, Republic of	11	281	853	3,310	1	13	--	--	625	3,600
Mexico	9	332	3	125	115	713	(6/)	5	39	1,170
Netherlands	164	4,220	189	2,680	--	--	--	--	300	6,910
Sweden	23	191	2	68	--	--	--	--	24	259
Taiwan	2	78	7	95	20	183	(6/)	4	12	361
United Kingdom	67	2,030	5	218	--	--	--	--	71	2,250
Other	96	2,660	50	854	4	38	--	--	133	3,550
Total	2,240	57,300	1,260	10,200	209	1,510	44	462	3,210	69,400

-- Zero.

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

2/ In addition to the materials listed, the United States exports cobalt ores and concentrates and wrought cobalt and cobalt articles.

3/ Includes unwrought cobalt, powders, waste and scrap, and mattes and other intermediate products of cobalt metallurgy.

4/ Free alongside ship (f.a.s.) value.

5/ Estimated from gross weights.

6/ Less than 1/2 unit.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 7
WORLD ANNUAL COBALT REFINERY CAPACITY
DECEMBER 31, 2001 1/ 2/

(Metric tons, cobalt content)

Country	Capacity
Australia e/	3,900
Belgium	1,200
Brazil	800
Canada	5,100
China e/	4,200
Congo (Kinshasa)	17,000
Finland	10,000
France	300
India	370
Japan	480
Morocco	1,200
Norway	4,500
Russia e/	8,000
South Africa e/	1,000
Uganda e/	650
Zambia	9,000
Total	67,700

e/ Estimated.

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

2/ Refinery products include cobalt metal, metal powder, oxides, and/or salts.

TABLE 8
COBALT: WORLD MINE PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, cobalt content)

Country 3/	1997	1998	1999	2000	2001 e/
Australia e/ 4/	3,000	3,300	4,100	5,600	6,200
Botswana 5/	334	335	331	308 r/	325 6/
Brazil e/	400	400	700	900	1,100
Canada 7/	5,709	5,861	5,323	5,298 r/	5,334 6/
China e/	200	40	250	90 r/	150
Congo (Kinshasa) e/ 8/	3,500	5,000	6,000	7,000	4,700
Cuba 9/	2,358 r/	2,665 r/	2,537 r/	2,943 r/	3,411 6/
Kazakhstan e/ 10/	300	300	300	300	300
Morocco 11/	714	287	863	1,305	1,300
New Caledonia e/ 12/	1,000	1,000	1,100	1,200 r/	1,400
Russia e/	3,300	3,200	3,300	3,600	3,800
South Africa e/	465	435	450	580 r/	550
Zambia 11/ 13/	6,037	11,900	5,640	4,600	8,000
Zimbabwe e/ 14/	126	138	121	79 r/ 6/	95 6/
Total	27,400 r/	34,900 r/	31,000 r/	33,800 r/	36,700

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 18, 2002. Figures represent recoverable cobalt content of ores, concentrates, or intermediate products from copper, nickel, platinum, or zinc operations. Morocco was the only country where cobalt was mined as a primary product.

3/ In addition to the countries listed, Bulgaria, Indonesia, Philippines, and Poland are known to produce ores that contain cobalt, but information is inadequate for reliable estimates of output levels. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.

4/ Quantities of cobalt contained in intermediate or refined metallurgical products produced from Australian and imported ores. Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate originating in Australia was estimated as follows, in metric tons: 1997--1,600; 1998--4,000; 1999--7,000; 2000--5,100; and 2001--6,100.

5/ Reported cobalt content of pelletized nickel-copper matte.

6/ Reported figure.

7/ Assay content of cobalt in concentrates produced. The cobalt content of all products derived from ores of Canadian origins, including cobalt oxide shipped to the United Kingdom for further processing and nickel-copper matte shipped to Norway for refining, was reported as follows, in metric tons: 1997--2,168; 1998--2,262; 1999--2,014; 2000--2,022 (revised); and 2001--2,048.

8/ Cobalt content of concentrates and tailings.

9/ Determined from reported nickel-cobalt content of sulfide production.

10/ Estimated cobalt content of only those ores from which it is assumed cobalt is recovered. Cobalt content of total ores mined is assumed to be as follows, in metric tons: 1997-2001--1,400.

11/ Cobalt content of concentrates.

12/ Quantities of cobalt contained in intermediate or refined metallurgical products (cobalt chloride, cobalt oxide-hydroxide, and cobalt sulfide) produced from New Caledonian ores exported to Australia and France. Cobalt content of total ores mined is estimated as follows, in metric tons: 1997--13,600; 1998--12,500; 1999--11,000; and 2000-01--12,000.

13/ 1997-98 are fiscal years beginning April 1; 1999-2001 are calendar years.

14/ Cobalt content of intermediate products produced in Zimbabwe from ores originating in Botswana and Zimbabwe.

TABLE 9
COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, cobalt content)

Country 3/	1997	1998	1999	2000	2001
Australia, metal (including metal powder) and oxide hydroxide	617	1,395	1,700 e/	2,610 r/ e/	3,470 e/
Belgium, metal powder, oxide, hydroxide e/	1,200	1,200	950	1,110	1,090
Brazil, metal	266	364	651	792	889
Canada, metal (including metal powder) and oxide	3,792	4,415	4,196	4,364 r/	4,378
China, metal e/	470	410	300	410 r/	450
Congo (Kinshasa), metal 4/	2,808	4,490	5,180	4,320	4,071
Finland, metal powder and salts	5,000	5,250	6,200	7,700	8,100
France, chloride	159	172	181	204	199
India, metal and salts e/	110	120	120	206	250
Japan, metal	264	329	247	311	350
Morocco, metal	225	242	472	1,200	1,200
Norway, metal	3,417	3,851	4,009	3,433	3,314
Russia, unspecified e/	4,100	3,500	3,600	4,400	5,000
South Africa, metal powder and sulfate	316	296	306	397	371
Uganda, metal	--	--	77	420	634
Zambia, metal 5/	4,403	4,837	4,236	3,342	4,657
Total	27,100	30,900	32,400	35,200	38,400

e/ Estimated. r/ Revised. -- Zero.

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 18, 2002. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

3/ In addition to the countries listed, Germany and Slovakia may produce cobalt, but available information is inadequate to make reliable estimates of production.

4/ Excludes production of cobalt in white alloy, matte, and slag that would require further refining.

5/ 1997-98 are fiscal years beginning April 1; 1999-2001 are calendar years.