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 alloys designed to resist stress and corrosion at high temperatures. The main use for superalloys is in jet engine parts. Another important use of cobalt is to make permanent magnets, which are used in a wide range of electrical devices. Cobalt metal powder acts as a binder in cemented carbides and diamond tools, which are used for metal cutting and forming, mining, and oil and gas drilling. Cobalt compounds are used in catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; ground coats for porcelain enamels; pigments for ceramics, paints, and plastics; battery electrodes; steel-belted radial tires; and magnetic recording media.

The United States is the world's largest consumer of cobalt, but has no domestic production, so it relies on imports to meet its primary cobalt needs. The United States stocks significant quantities of cobalt metal in the National Defense Stockpile (NDS) for military, industrial, and essential civilian use during a national emergency.

World cobalt production decreased for the third year in a row. Most of the decrease occurred in Zaire, which fell from its historical position as the world's largest cobalt producer to sixth place. Decreasing prices during most of 1993 suggested that there were sufficient supplies of cobalt to meet demand. Russian cobalt, releases from Government and industry stocks, and production increases from Canada, Finland, and Norway contributed to supply, while recessionary economic conditions in some cobalt-consuming countries, decreased defense spending, and a drawdown of consumer stocks held back demand.

DOMESTIC DATA COVERAGE

Domestic data on cobalt processing and consumption are developed by the USBM from three separate, voluntary surveys of U.S. operations. In the cobalt processors survey, seven of the eight companies canvassed responded. Most of the data on cobalt chemical uses were obtained from this survey. The second survey covers a broad range of metal-consuming companies, such as superalloy producers, magnetic alloy producers, and tungsten carbide producers. For this survey, more than 100 cobalt consumers were canvassed on a monthly or annual basis. The USBM also canvasses 13 superalloy scrap recyclers to determine the consumption of secondary cobalt in superalloy production. The data in tables 3 through 6 contain estimates to account for nonrespondents.

BACKGROUND

Definitions, Grades, and Specifications

Cobalt is a metallic element. It is silvery gray in color, hard, ductile, somewhat malleable, and magnetic. Other properties include atomic number, 27; atomic weight, 58.93; melting point, 1,493° C; boiling point, 3,100° C; and Curie temperature, 1,121° C. Cobalt-60 (^{60}Co) is produced by irradiating cobalt metal in a nuclear reactor. This radioactive isotope is used in radiation therapy, for the sterilization of medical supplies, and more recently, to treat fresh foods.

Currently, there are no internationally recognized specifications for cobalt metal. The Zairian and Zambian cobalt producers proposed specifications for five grades of cobalt in 1988.[1] The U.S. Government has purchase specifications for NDS cobalt. The current NDS specification, P-13-R6, has been in effect since December 18, 1985. It provides physical and chemical requirements for three grades of refined cobalt metal. Grades A and B must be in the form of electrolytic cathode; grade C can be either cathode or granules. Chemical requirements specify the weight percentage, in order of abundance, of cobalt, nickel, iron, and manganese, as well as maximum levels of 26 impurities.

Products for Trade and Industry

Less than one-half of the cobalt used in the United States was consumed as primary cobalt metal. Most of this metal was in the form of electrolytic cobalt (cathode or rounds), granules (shot), ingot, or metal powder of various grades (particle-size ranges). About one-fourth of U.S. reported consumption in 1993

was from purchased scrap. Cobalt-bearing scrap originated from alloy processing, parts manufacturing, and used cobalt-containing products. The remainder of the cobalt used in the United States, about one-third of total consumption, was in the form of cobalt chemical compounds. These included cobalt oxide of various types, inorganic cobalt compounds (acetate, carbonate, chloride, hydroxide, nitrate, and sulfates), and organic cobalt compounds.

Industry Structure

More than 90% of the world's cobalt is refined in six countries: Canada, Finland, Norway, Russia, Zaire, and Zambia. Until recently, more than three-quarters of world production was from three countries: Zaire, Zambia, and Russia. Zaire was historically the dominant producer, supplying more than one-third of the world's refined cobalt. The ranking of the top six producing countries changed significantly in 1993. A drastic decrease in production caused Zaire to fall from its position as the world's largest producer to sixth place. Zambia became the world's largest producer. Varying estimates for Russian production place it somewhere between second and fifth place.

Zairian and Zambian production was from domestic ores. Canada and Russia produced cobalt from both domestic and imported raw materials. All of the cobalt produced in Norway and most of the cobalt produced in Finland was from imported raw materials. The United States was not a cobalt producer. U.S. mine production of cobalt ceased at the end of 1971, and the sole U.S. cobalt refinery discontinued processing imported nickel-cobalt matte in late 1985. World producers of refined cobalt and producers of intermediate cobalt-containing products are listed in tables 1 and 2. *(See tables 1 and 2.)*

Cobalt processors represent an important source of supply for various industries. Processors differ from producers in the feed materials they use, although some overlap exists. Producers refine cobalt primarily from materials originating from mining or refining operations—ores, concentrates, mattes, or residues—although some refineries supplement their feedstock with cobalt-bearing scrap. In contrast, processors use refined cobalt metal or cobalt-bearing scrap as feed materials. The world's largest cobalt processor is Union Minière S.A. in Belgium (formerly Metallurgie Hoboken-Overpelt S.A.).

Byproducts and Coproducts

Cobalt is rarely produced as the primary product of a mining or refining operation. Zaire and Zambia produce cobalt as a byproduct of copper. Cobalt production in most other countries is a byproduct of nickel. Exceptions are Morocco, where cobalt is produced as a primary product, and the Republic of South Africa, where cobalt is produced as a byproduct of platinum. Future production from Belgium will include cobalt recovery from residues produced during electrolytic zinc refining. A Canadian company plans to produce cobalt from old silver tailings.

Economic Factors

Most of cobalt's production costs are attributed to the primary metal produced at a given operation. The incremental costs applied to cobalt production include costs to separate cobalt from the primary metal, usually during the refining stage; transportation costs; and marketing costs.

Operating Factors

The U.S. Environmental Protection Agency (EPA) regulates releases of cobalt into the environment under various programs. Workplace exposures are regulated by the Occupational Safety and Health Administration (OSHA). In addition to these regulatory agencies, the following groups issue guidelines or develop scientific positions for consideration by Government agencies when making regulations: American Conference of Governmental Industrial Hygienists (ACGIH), International Agency for Research on Cancer (IARC), and Agency for Toxic Substances and Disease Registry (ATSDR). A review of U.S. environmental legislation and regulation pertinent to cobalt was presented in 1993.[2]

Effective March 23, OSHA reverted back to permissible exposure limits (PEL's) for air contaminants in place before January 19, 1989. The suspension of OSHA's stricter PEL's was the result of a 1992 Federal court decision that OSHA could not issue broad standards for hundreds of chemical substances without scientifically justifying changes to each individual standard. As a result of this change, the PEL for cobalt metal, dust, and fume reverted back to an 8-hour time-weighted average of 0.1 milligram per cubic meter of air (mg/m^3). PEL's set in January 1989 for previously unregulated cobalt carbonyl and cobalt hydrocarbonyl were revoked.

On May 18, ACGIH restated its intention to decrease its threshold limit value (TLV) for cobalt from an 8-hour time-weighted average of 0.05 mg/m^3 to 0.02 mg/m^3. ACGIH TLV's are used by regulatory agencies such as OSHA in setting permissible exposure levels. The proposed change in the TLV was still under consideration at yearend.

ANNUAL REVIEW

Legislation and Government Programs

On March 24, 1993, the Defense Logistics Agency (DLA) began bimonthly sales of cobalt from the NDS. The sales were intended to bring the NDS cobalt inventory down to the goal set in the Department of Defense (DOD) 1992 Report to the Congress on National Defense Stockpile Requirements. Approximately 113 metric tons (250,000 pounds) of cobalt granules was available for sale on the second Wednesday of each month and 45 tons (100,000 pounds) of cobalt rondelles was available on the fourth Wednesday of each month. In August, the DLA increased the quantity of cobalt rondelles available each month to 68 tons (150,000 pounds). In September, the DLA decreased the quantity of cobalt granules available each

month to 91 tons (200,000 pounds).

The quality of the cobalt for sale by the DLA reflects the technological requirements in existence at the time of its purchase more than 30 years ago. The cobalt content of the granules ranged from 99.20% to 99.83% and the cobalt content of the rondelles ranged from 98.16% to 99.60% cobalt. During the year, the DLA accepted bids at prices close to those quoted by Metal Bulletin for 99.3% cobalt ingot from Russia. Participants in the bidding included trading firms, chemical processors, alloy producers, a scrap processor, a metal powder processor, and a copper refiner.

The DLA sold 276 tons of cobalt during fiscal year 1993 (October 1, 1992, through September 30, 1993). Sixty percent of the sales was cobalt rondelles (164 tons) and 40% was cobalt granules (112 tons). The sales represented just 13% of the quantity allowable for sale under the Annual Materials Plan (AMP) for the fiscal year—2,087 tons (4.6 million pounds). According to DLA's AMP for fiscal year 1994, the maximum amount of cobalt that could be sold in the year beginning October 1, 1993, also would be 2,087 tons (4.6 million pounds).

The DLA sold 418 tons of cobalt during calendar year 1993. Fifty-eight percent of the sales was cobalt granules (244 tons) and 42% was cobalt rondelles (174 tons). At yearend, the total uncommitted cobalt inventory reported by the DLA was 23,650 tons, contained cobalt. The DOD revised the NDS requirement for cobalt to zero in its 1993 Report to the Congress on National Defense Stockpile Requirements. However, the DOD did not recommend adopting new NDS goals until a DOD strategic review was completed and updated ratios relating demand for manufactured goods to demand for strategic and critical materials were received from the Department of Commerce. At that time DOD was to reestimate NDS requirements and submit a revised set of requirements to Congress.

Strategic Considerations

Cobalt is considered a strategic and critical metal because of its many industrial and defense-related uses and because the United States is highly dependent on imports for its supply. The United States is the world's largest consumer of cobalt. In 1993, the United States consumed about 40% of estimated world refinery production. There was no domestic production, so demand was met primarily from imports, with the exception of about 20% to 25% from purchased scrap.

To ensure an adequate supply for military, industrial, and essential civilian needs, cobalt metal is included in the NDS. Stockpile quantities are intended to sustain the United States for a period of not less than 3 years during a national emergency situation. However, most of the cobalt in the stockpile was purchased prior to 1980 and does not meet current quality requirements for vacuum-melted superalloys.

World cobalt production is concentrated in a limited number of geographic areas. More than one-half of the world's refined cobalt is produced in three countries: Russia, Zaire, and Zambia. Political and economic conditions in the producing countries can impact cobalt production, transportation, and/or exports.

Production

There was no domestic mine or refinery production of cobalt in 1993. Formation Capital Corp., of Vancouver, British Columbia, acquired and explored the Blackpine property southwest of Salmon in Lemhi County, ID. The Blackpine property is a copper-cobalt-gold-silver sulfide deposit in the same mineral belt that contains Noranda Mining Inc.'s Blackbird Mine. Formation Capital's exploration program included geophysics, soil geochemistry, trenching, and drilling. The company is considering three options for possible development: open pit mining followed by heap leaching and solvent extraction; open pit mining followed by milling; and underground mining on the higher grade beds.[3]

U.S. cobalt supply included secondary cobalt from the recycling of superalloy and other forms of scrap. Cobalt was recovered from spent petroleum catalysts at the AMAX Metals Recovery plant in Braithwaite, LA, and by Gulf Chemical and Metallurgical Corp. in Freeport, TX.

Hecla Mining Co. produced cobalt chemicals at its Apex Unit's hydrometallurgical processing plant in St. George, UT. The company reported sales of more than 43 tons of cobalt chemicals in 1993.[4] Hecla continued process trials of cobalt-bearing residues, with plans to develop a business based on the recycling of residues and other cobalt-bearing feedstocks.

Two cobalt processors produced extra-fine cobalt metal powder in the United States. Carolmet, owned by Union Minière of Belgium, produced cobalt metal powder from imported primary metal at its Laurinburg, NC, plant. Osram Sylvania Inc. (formerly GTE Products Corp.) produced cobalt metal powder from recycled materials in Towanda, PA. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

Domestic cobalt processors produced 1,979 tons of cobalt contained in cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds in 1993, essentially the same amount as the 1,969 tons produced the previous year. Because this figure includes production of intermediate forms, it does not represent net production. Shipments are defined as sales, transfers, or consumption to make end-use products such as paint driers or catalysts. In 1993, shipments by domestic cobalt processors included 1,793 tons of cobalt contained in cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds, a slight decrease from 1992 shipments of 1,838 tons.

Consumption and Uses

Apparent consumption, as calculated

from net imports, consumption from purchased scrap, and changes in Government and industry stocks increased 12% in 1993 to approximately 7,300 tons. The following factors contributed to the increase: cobalt was shipped from the NDS, industry stocks continued to decrease, and much less cobalt was exported. U.S. reported consumption was unchanged from reported consumption in 1992. As a whole, metallurgical industries consumed approximately the same amount of cobalt in 1993 as they did in 1992. On an industry-by-industry basis, cobalt consumption by superalloy melters and magnetic alloy producers decreased in 1993, while cobalt consumption by producers of cemented carbides, welding materials, mill products from metal powders, steel, and other alloys increased. Total cobalt consumption for chemical uses was essentially unchanged in 1993 as compared with 1992. *(See tables 3, 4, and 5 and figure 1.)*

Stocks

The total amount of cobalt contained in stocks held by U.S. processors and consumers was basically the same as that at yearend 1992. However, 1993 yearend stocks of cobalt metal and scrap were slightly higher than those of 1992 and 1993 yearend stocks of cobalt chemicals were 11% lower than stocks of cobalt chemicals at yearend 1992. *(See table 6.)*

Markets and Prices

During most of 1993, the U.S. spot price for cobalt cathode reported by Platt's Metals Week continued to decline from the high levels of December 1991-January 1992. The highest prices during the year occurred in February and March when the price of cathode increased to $16 to $16.50 per pound. The brief increase in cathode price was in response to reports of renewed violence in Zaire and a tightening of supplies of lower quality Russian cobalt. By mid-March the cathode price resumed its decline and dropped below $11 per pound by early December. The decrease was attributed to weak demand, particularly from Europe and Japan, consumption from stocks, and availability of cobalt on the free market. Russian cobalt imports to Western markets and regular offers of NDS cobalt from the DLA contributed to total cobalt supply, although cobalt from these sources was low quality.

In mid-December, free market prices for both cathode and Russian cobalt rapidly increased. By yearend, the price of cathode was $15 per pound and Russian cobalt exceeded $14 per pound. These price increases reflected a growing concern over cobalt supply prompted by the following factors: delays by the African producers in announcing their 1994 pricing policy; consumers' reduced stock levels resulting from buying on an as-needed basis; press reports that Zaire's Shaba Province, where the copper-cobalt industry is located, declared autonomy from the rest of the country; expectations for reduced production in 1994 from Zambia and from Canadian producer Inco Ltd.; and traders' reports of reduced supplies of Russian cobalt. However, the magnitude and speed of the price increases suggest trader manipulation. Platt's Metals Week reported an average annual U.S. spot cobalt cathode price of $13.79 per pound for the year. *(See table 3 and figure 2.)*

Metal Bulletin reported free market prices for two grades of cobalt—minimum 99.3% cobalt from Russia and higher quality minimum 99.8% cobalt. Prices for the two grades of cobalt more or less paralleled one another, although price increases and decreases for Russian cobalt tended to be steeper than those for the 99.8% cobalt. In January, price quotes for Russian cobalt were $3 to $4 per pound lower than quotes for higher quality cobalt. The price differential narrowed to $2 per pound by March and to $1 per pound in August. In December, price quotes for Russian cobalt overlapped quotes for higher quality cobalt.

The 1993 cobalt producer price was set by La Générale des Carrières et des Mines (Gécamines) of Zaire and Zambia Consolidated Copper Mines Ltd. (ZCCM) at $18 per pound in November 1992. Because of the increasing differential between the producer price and lower free market prices, the African producers reportedly began using free market price quotes as the basis of their transactions by mid-1993.[5] The 1993 price expired on November 20, 1993. At yearend, a new producer price had not been set for 1994. *(See table 7.)*

Foreign Trade

U.S. imports of unwrought cobalt and cobalt in chemicals increased slightly in 1993. More than 90% of these imports was supplied by six countries. Zambia was the leading supplier of cobalt to the United States, followed by Norway, Canada, Finland, Zaire, and Russia. Cobalt imports from Finland, Norway, and Russia increased significantly in 1993 as compared with imports in 1992. *(See tables 8 and 9 and figure 3.)*

In 1993, the United States imported 175 tons, gross weight, of unwrought cobalt alloys valued at $4.7 million. Five countries supplied 94% of these materials: the United Kingdom (53%), Sweden (18%), the Republic of South Africa (14%), France (5%), and Belgium (3%). The United States imported 405 tons, gross weight, of cobalt matte, waste, and scrap, valued at $4.3 million. Four countries supplied 82% of these materials: the United Kingdom (41%), Germany (21%), Japan (15%), and Russia (5%). The United States also imported 172 tons, gross weight, of wrought cobalt and cobalt articles valued at $7.9 million. The leading suppliers of these materials were the United Kingdom (41%) and Japan (30%), followed by Germany (9%), France (6%), and Canada and the Netherlands (5% each).

U.S. net import reliance as a percentage of apparent consumption was estimated to be 79% in 1993. The net import reliance would be 100% if no cobalt was recovered from secondary sources (scrap).

The import duty on cobalt acetates, carbonates, and chlorides was 4.2% ad valorem for most favored nations (MFN) and 30% ad valorem for non-MFN. The

duty on cobalt oxides and hydroxides was $0.026 per kilogram for MFN and $0.44 per kilogram for non-MFN. The duty on cobalt sulfates was 1.4% for MFN and 6.5% for non-MFN. Imports of unwrought cobalt metal; cobalt ores and concentrates; and cobalt matte, waste, and scrap were duty free. The duty on unwrought cobalt alloys and wrought cobalt and cobalt articles was 5.5% for MFN and 45% for non-MFN. Special rates of duty are applied to certain cobalt-containing materials under the following programs: Andean Trade Preference Act, Caribbean Basin Economic Recovery Act, Generalized System of Preferences, United States-Canada Free-Trade Agreement, and the United States-Israel Free Trade Area.[6]

U.S. exports of unwrought cobalt and cobalt contained in chemicals decreased 44% as compared with exports in 1992. More than three-quarters of this cobalt was shipped to seven countries: Brazil, Canada, Indonesia, Japan, Mexico, Taiwan, and the United Kingdom. The remainder was shipped to 39 other countries. *(See table 10.)*

Exports also included 249 tons, gross weight, of wrought metal and cobalt articles valued at $11.4 million. More than three-fourths of these materials was sent to eight countries: Canada and the Republic of Korea (each 16%); Norway (10%); France, Sweden, and the United Kingdom (each 8%); and Belgium and Japan (each 6%). The remainder was shipped to 21 other countries. In addition, the United States exported 9 tons, gross weight, of material under the category entitled, "Cobalt ores and concentrates." The material, valued at $77,755, was sent to Canada.

World Review

World cobalt production decreased for the third consecutive year in 1993. Refinery production reported by the seven Cobalt Development Institute (CDI) member producers—Falconbridge Ltd.; Gécamines; Inco Ltd.; OM Group, Inc.; Sherritt Inc. (formerly Sherritt Gordon Ltd.); Sumitomo Metal Mining Co. Ltd.; and ZCCM—decreased 23% from 17,891 tons in 1992 to 13,843 tons in 1993.[7] The decrease was primarily due to the continuing decrease in production by Gécamines, dropping Zaire out of its historical position as the world's largest cobalt producer. If production by Gécamines is excluded, production by the remaining six CDI member producers shows an increase of 3% as compared to production in 1992. Three producers, Falconbridge, OM Group, and Sherritt, reported record-high production levels in 1993. Production by Sumitomo also increased, while production by Inco and ZCCM decreased.

The CDI estimated the following additional cobalt supplies available to Western consumers in 1993: 3,000 tons in nonconsumer stocks from yearend 1992; 1,000 tons produced in Brazil, China, France, and the Republic of South Africa; 420 tons released from the NDS; and 2,000 tons exported from Russia. This resulted in a total availability of approximately 20,260 tons. The CDI concluded that, assuming Western demand was similar to that of 1992 at 19,200 tons, 1993 supply and demand were roughly in balance.

Capacity.—The data in table 11 are rated capacity for refineries as of December 31, 1993. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical reported or estimated cobalt production data have been used to estimate refinery capacity in some cases. Changes in refinery capacity can result from changes in facilities, changes in the grade of raw materials processed, and/or changes in knowledge about the facilities. *(See table 11.)*

Australia.—QNI Ltd. produced cobalt sulfide from nickel laterites at the Yabulu nickel-cobalt refinery in Townsville, Queensland. About 85% of the feed for the refinery was imported from Indonesia and New Caledonia. The remainder was from the company's Brolga mine in Queensland, which came on-stream in 1993. During the year the company worked on the construction of a pilot plant for upgrading its cobalt sulfide to value-added products. QNI's cobalt sulfide is currently refined to cobalt metal powder, oxide, and salts by OM Group's Kokkola Chemicals Oy refinery in Kokkola, Finland. Kokkola Chemicals' contract to purchase QNI's cobalt sulfide expires at yearend 1996.

Western Mining Corp. (WMC) produced intermediate cobalt products as a byproduct of mining, smelting, and refining nickel sulfide ores in Western Australia. Some of the nickel-copper-cobalt matte produced at WMC's Kalgoorlie smelter was exported to other refiners, including Sumitomo Metal Mining Co. of Japan. The remainder was refined by WMC at its Kwinana nickel refinery. The Kwinana refinery produced cobalt in a nickel-cobalt mixed sulfide. The mixed sulfide has traditionally been refined by Sherritt Inc. in Canada.

WMC continued its evaluation of the Bulong nickel-cobalt laterite deposit east of Kalgoorlie in Western Australia. The company has been investigating the recovery of nickel and cobalt by acid pressure-leaching at high temperatures. Sulfuric acid for the process could be produced from sulfur dioxide generated at WMC's Kalgoorlie smelter. Current annual production estimates from Bulong are 18,000 tons of nickel and 1,200 tons of cobalt.[8]

MIM Holdings Ltd. continued pilot plant studies on the recovery of cobalt from its Mount Isa copper concentrates by bioleaching. Potential production was estimated at 600 tons of cobalt per year.[9]

Cobalt Resources N.L. was incorporated in May to explore and develop manganese-cobalt deposits in the

Mount Tabor district 125 km northeast of Augathella in central Queensland. The deposits are in the form of cobalt mineralization associated with manganiferous wads (a soft mixture of manganese and other oxides formed in weathering zones). The company planned an exploration program to locate all potential cobalt-bearing occurrences, define minable deposits, and prove reserves. The exploration target was 3 million tons of ore averaging 0.3% cobalt. Based on previous laboratory-scale testing by Commonwealth Scientific and Industrial Research Organization (CSIRO), the following process flowsheet was proposed. Run-of-mine ore would be crushed, then acid leached under agitation with added sulfur dioxide gas. The leached pulp would undergo a solid/liquid separation, cobalt would be selectively recovered by solvent extraction, then cobalt metal would be produced by electrowinning.[10]

Belgium.—Union Minière (UM) converted cobalt metal, residues, and other cobalt-bearing materials into cobalt metal powders, oxides, hydroxide, and chloride at its facilities in Olen, Belgium. During the year, UM developed a process to recover cobalt from residues generated during zinc refining. The company upgraded its Olen facilities to treat a wider range of cobalt-bearing feeds and to increase the throughput of secondary materials from 50 tons per month to 100 tons per month. By treating more secondary materials, UM planned to reduce its annual purchases of cobalt metal by several hundred tons.[11]

Botswana.—BCL Ltd. mined nickel-copper ores from company mines in the Selebi-Phikwe district. Copper-nickel-cobalt matte produced by BCL was sent to refineries in Norway and Zimbabwe to be refined. BCL is 85% owned by Botswana RST Ltd. (BRST). At midyear, Amax Inc. sold its 29.8% interest in BRST to the Botswanan Government.

Brazil.—Cia. Niquel Tocantins produced cobalt cathode at its nickel refinery in Sao Miguel Paulista, Sao Paulo State.

Canada.—Cobalt was produced as a byproduct of nickel by three Canadian companies, Falconbridge, Inco, and Sherritt. In 1993, Falconbridge produced 800 tons of cobalt from nickel-copper ores at its Sudbury, Ontario, operations.[12] Cobalt-containing nickel-copper matte from the Sudbury smelter was refined at Falconbridge's Nikkelverk refinery in Norway.

Inco produced cobalt oxide at its Thompson, Manitoba, refinery and cobalt cathode at its Port Colborne refinery. Feed materials for the two refineries originated from nickel mines in Thompson, Manitoba, and Sudbury, Ontario, respectively. In response to excess supply in the nickel market, Inco reduced its nickel production by 8% in 1993. Production of byproduct cobalt decreased 4%. Inco refined 1,410 tons of cobalt in 1993 as compared with 1,465 tons in 1992.[13]

Sherritt refined nickel-cobalt materials from Australia, Canada, Cuba, and the Republic of South Africa at its Fort Saskatchewan refinery in Alberta. During 1993, Sherritt completed the expansion of its nickel-cobalt refinery. The refinery uses a new cobalt-nickel separation process that can treat a wider range of feed materials. At yearend, the cobalt plant was operating at an annual rate of about 1,600 tons (3.5 million pounds). During a plant performance run in the first quarter of 1994, the cobalt plant was run at the design capacity of about 2,000 tons (4.5 million pounds). In 1993, Sherritt produced a record 1,218 tons of cobalt, an increase of 78% over the 686 tons of cobalt produced in 1992.[14]

Cobatec Ltd., a wholly owned subsidiary of Ego Resources Ltd. of Toronto, developed a hydrometallurgical process to produce cobalt from silver-cobalt tailings and ores from the historic silver mining town of Cobalt, in eastern Ontario. The process involved pressure leaching in the presence of oxygen, solvent extraction, then electrolysis to produce cobalt cathode and byproduct nickel cathode. Ego Resources was considering adjusting the process to produce cobalt compounds. The company planned to begin construction in 1994 of a plant with the capacity to produce approximately 300 tons of cobalt per year. Ego Resources reported that it had acquired sufficient feed for approximately 4 years of full production and planned to acquire additional feed to extend production.[15]

In June 1993, the British Columbia government designated the Tatshenshini-Alsek region in northwestern British Columbia as a protected wilderness area, thus preventing any future development of mineral claims in the region. Geddes Resources Ltd. of Vancouver, British Columbia, terminated the permitting process for its Windy Craggy copper-cobalt-gold deposit and began seeking compensation from the government. The deposit had been called "Canada's largest undeveloped source of cobalt."[16] The company estimated reserves at 297 million tons of ore grading 1.38% copper, 0.069% cobalt, 3.83 grams silver per ton, and 0.2 gram gold per ton.[17]

China.—Cobalt was produced at various locations in China from both domestic and imported raw materials. At Jinchuan, Gansu Province, cobalt metal was produced as a byproduct of nickel from the refining of domestic nickel sulfide ores. The Ganzhou cobalt refinery in Jiangxi Province produced cobalt metal and salts from cobalt arsenide concentrates imported from Morocco. Minor production sites included the Zibo Cobalt Works in Shandong Province, where cobalt metal was produced from iron ore from Shandong Province and copper ore from Shanxi Province.

Côte d'Ivoire.—Falconbridge Ltd. and Trillion Resources Ltd. of Canada signed an agreement with Société de Développement Minière de la Côte d'Ivoire (SODEMI) for the exploration of nickel-cobalt laterite deposits near Biankouma, western Côte d'Ivoire. CRU International Ltd. estimated an annual

cobalt output of 1,300 tons in a sulfide precipitate, with 1998 as the earliest startup date for the project.[18]

Cuba.—Unión de Empresas del Níquel (UNI) produced nickel-cobalt sulfides at its Moa Bay plant and nickel-cobalt oxide and oxide sinter at its Nicaro and Punta Gorda plants. All three plants used Cuban laterites as their feedstock. The nickel-cobalt sulfides contained a greater percentage of cobalt than the oxide and sinter, roughly 5% as compared with about 1%. Historically, all of the sulfides were refined at the Yuzhural Nickel refinery at Orsk in the southern Ural Mountains in Russia. Since 1991, some of the sulfides have been refined at Sherritt's Fort Saskatchewan nickel-cobalt facility in Canada. Reports indicate that in 1993, two-thirds of the nickel-cobalt sulfides from Moa Bay were sent to Sherritt and approximately 3,000 tons of sulfides were sent to Yuzhural Nickel.[19]

UNI continued with plans to produce cobalt from its nickel-cobalt intermediate materials. The company hoped to begin production within 5 years, assuming foreign investment was secured to develop the nickel-cobalt separation technology. The cobalt separation plant would be built at UNI's fourth nickel refinery, currently under construction at Las Camariocas. Nickel-cobalt intermediate materials from all four of UNI's nickel refineries would be treated at Las Camariocas. Output from the cobalt plant was forecast at 3,000 tons nickel and 1,000 tons cobalt.[20]

Finland.—In June, Outokumpu Metals & Resources Oy decided to expand and upgrade its Harjavalta nickel refinery. Feed for the Harjavalta refinery was traditionally from Finnish nickel mines. As ore reserves in Finland declined, Outokumpu has imported an increasing amount of its nickel feed from Western Australia. The shift from high-copper Finnish concentrates to high-magnesia Australian concentrates created the need for a change in the refining process. As part of the expansion and upgrade, Outokumpu designed a circuit to refine its cobalt hydroxide sludge to cobalt metal powder. Annual cobalt output was expected to double from about 250 tons to about 500 tons of contained cobalt. Feed for Harjavalta would be primarily concentrates from Outokumpu's Forrestania Mine, which is currently producing, and WMC's Mount Keith Mine, which was expected to begin production in 1995.

In October, Outokumpu sold its entire 96% share of OM Group, Inc. in a public offering. OM Group was formed in October 1991 when Outokumpu and U.S.-based Mooney Chemicals, Inc. merged their chemical businesses. OM Group produces cobalt products at three locations: Kokkola, Finland; Ezanville, France; and Franklin, PA. In 1993, OM Group's Kokkola Chemicals Oy refinery produced a record 2,200 tons of cobalt in cobalt metal powders, oxides, and salts.[21] The refinery uses cobalt sulfide from QNI Ltd. in Queensland, Australia, cobalt slag from Gécamines in Zaire, and cobalt hydroxide sludge from Outokumpu's Harjavalta refinery as its raw materials feed. OM Group planned to build a facility at Kokkola in 1994 to produce carboxylates for the European market.[22] Cobalt carboxylates are used by chemical processing, coatings, and tire industries.

Indonesia.—State-owned PT Aneka Tambang (ANTAM) was under contract to supply 1 million wet tons of lateritic nickel ore to QNI Ltd.'s Yabulu nickel-cobalt refinery in Queensland, Australia. The ore was to come from ANTAM's Oeboelie Mine on Gebe Island in eastern Indonesia.

Japan.—Sumitomo produced electrolytic cobalt, cobalt oxide, and cobalt salts as a byproduct of nickel production at its Niihama Nickel Refinery in Ehime Prefecture. According to Japan's Ministry of International Trade and Industry (MITI), 1993 Japanese cobalt consumption increased 8% to 2,417 tons. Cobalt consumption by industry was reported as follows: cobalt in catalysts increased 8% to 385 tons, cobalt in hard-metal tools decreased 6% to 276 tons, cobalt in magnetic materials increased 15% to 547 tons, cobalt in specialty steels increased 6% to 691 tons, cobalt in tube, plate, rod, and wire increased 15% to 234 tons, and cobalt in other uses increased 16% to 285 tons. Japanese demand for cobalt was met primarily from imports. Japan imported 4,009 tons of cobalt in 1993, a slight decrease from the 4,275 tons imported in 1992. Industry stocks also contributed to supply. In 1993, industry stocks decreased from 1,437 tons of cobalt at the beginning of the year to 1,110 tons at yearend.[23]

Mexico.—International Curator Resources Ltd. of Vancouver, British Columbia, began diamond drilling the Boleo copper-cobalt property near Santa Rosalia, Baja California. The drilling program was designed to confirm and expand the known reserves, quantify the cobalt content, and provide information on rock mechanics. Ore samples were sent for metallurgical testing to confirm the use of solvent extraction-electrowinning to process the ore.

New Caledonia.—Three New Caledonian mining companies were under contract to supply lateritic nickel ore to QNI's Yabulu nickel-cobalt refinery in Queensland, Australia. J.C. Berton Mines was to supply 500,000 wet tons of ore from its Bienvenue Mine, Nickel Mining Corp. was to supply 800,000 wet tons from its Kouaoua Mine, and Société des Mines de la Tontouta was to supply 300,000 wet tons from its Moneo and Nakety Mines.

Inco continued exploring the Goro nickel-cobalt property in southern New Caledonia. A bulk sample of lateritic ore was sent to Inco's research laboratory in Mississauga, Ontario, for extraction trials.

Norway.—The Falconbridge Nikkelverk refinery produced a record 2,414 tons of cobalt cathode in 1993,[24] a 5% increase from the previous record of 2,293 tons set in 1992. Feedstock for the refinery was in the form of matte from

company operations in Sudbury, Canada; BCL Ltd. in Botswana; and Norilsk Nickel in Russia. During the past few years, Falconbridge has gradually increased the Nikkelverk refinery's annual cobalt capacity from 2,000 tons to 2,600 tons.

Russia.—Most of the cobalt produced in Russia is a byproduct of Russian nickel mining and/or refining. Nickel and cobalt production in Russia involves a complex flow of ores, concentrates, and mattes between various production sites. Russian nickel-cobalt production is organized into two "Complexes." Norilsk Nickel Complex's production is from nickel sulfide ores mined, smelted, and refined at Norilsk in eastern Siberia and at various locations on the Kola Peninsula. In recent years, Norilsk Nickel has also toll-refined nickel and cobalt-bearing scrap and residues at its Monchegorsk refinery at Kola. Yuzhural Nickel Complex's smelters and refineries are in the Ural Mountains. Feedstock to Yuzhural Nickel's plants has included nickel laterites mined from the Ural region, cobalt-arsenide concentrates mined and beneficiated in the Tuva Autonomous Republic, nickel-cobalt sulfides from Cuba, and white alloy from Zaire.

Cobalt mine and refinery production in tables 12 and 13 for the former U.S.S.R. and Russia were increased based on estimated production from various sources. Production estimates for 1993 ranged from 1,850 tons to 4,200 tons. Russian cobalt continued to enter Western markets in 1993, although reportedly at lower levels than those of the previous year. Russian cobalt exports in 1993 were estimated at 1,000 to 3,000 tons.

South Africa, Republic of.—Cobalt was produced as a byproduct of South Africa's platinum industry. Two companies produced refined cobalt: Rustenburg Base Metal Refiners Pty. Ltd. produced cobalt sulfate and Impala Platinum Ltd. produced cobalt metal powder. A third company, Western Platinum Ltd., produced nickel sulfate containing minor amounts of cobalt. Most of South Africa's cobalt was exported.

According to preliminary figures from South Africa's Minerals Bureau, South African cobalt production decreased 27% in 1993 to 172 tons. Local cobalt sales decreased to 46 tons in 1993 from 50 tons in 1992. Exports of cobalt from South Africa decreased to 196 tons in 1993 from 211 tons in 1992.

Taiwan.—Mechema Chemicals International began production of cobalt acetate catalysts in Taiwan. The company purchased the Mechema name, technology, and plant facilities from Mechema Chemicals Ltd. of Port Talbot, Wales. The Welsh plant was dismantled, then rebuilt in Taoyuan. Cobalt acetate catalysts are used in the production of terephthalic acid, which is used to produce polyester textile fibers and polyethylene terephthalate films and bottles.

Tanzania.—Sutton Resources Ltd. and BHP Minerals International Exploration Inc. continued drilling nickel sulfide deposits in the Kabanga region of northwestern Tanzania and began drilling in the adjacent Kagera region. Sutton reported a resource at Kabanga of 25.5 million tons ore at 1.19% nickel, 0.20% copper, and 0.10% cobalt.

Uganda.—In September, the Kasese Cobalt Co. Ltd. completed a detailed feasibility study on the extraction of cobalt from cobaltiferous pyrites stockpiled at the Kilembe copper mines. The Kasese Cobalt Co. is a joint venture between Uganda's state-owned Kilembe Mines Ltd. (45%), Bureau de Récherches Geologiques et Minières (BRGM) of France (27.5%), and Barclays Metals Ltd. of the United Kingdom (27.5%). The study recommended the construction of a bioleaching-solvent extraction-electrowinning plant to produce 1,000 tons of cobalt cathode per year. The recommendations were based on an extensive analysis of the stockpile, followed by tests on an 8-ton sample at BRGM's laboratories in Orleans, France. A pilot plant was built in Uganda to assist with the engineering design of the commercial plant and training of the plant operators. By yearend, financing for the project was underway with a guarantee of $10 million for direct project investment by the World Bank's Multilateral Investment Guarantee Agency and $40 million insurance to commercial banks lending funds for the project.

Zaire.—The political stalemate in Zaire persisted through 1993, causing sporadic periods of political and social unrest, the postponement of much-needed foreign investment, rampant inflation, and continued shortages of consumables and spare parts at state-owned Gécamines. Under these adverse conditions, Gécamines' cobalt production continued to decrease. In 1993, cobalt supply to Gécamines' concentrators (cobalt content of ore milled) decreased to about 5,000 tons from 13,300 tons in 1992. As a result, the cobalt content of concentrates produced decreased to about 2,500 tons from 5,700 tons in 1992. Gécamines 1993 cobalt production dropped to about 2,100 tons from 6,600 tons produced in 1992. These figures include cobalt in matte, slag, and alloys that require further refining before they can be used by consumers. In terms of finished cobalt (cathode from the Luilu refinery and granules and low-quality cathode from Shituru), Gécamines produced only 831 tons in 1993 as compared with 5,049 tons in 1992. As a result of this large decrease in production, Zaire fell from its historical position as the world's largest cobalt producer to sixth place.

In 1993, increased amounts of cobalt-bearing materials were exported from Zaire to be refined. Early in the year, Gécamines sent 45,000 wet tons of cobalt slag from its Lubumbashi smelter to OM Group's Kokkola refinery in Finland. OM Group took delivery and title to the slag, but was not required to pay for it until it was refined. Gécamines also reportedly sent white alloy and matte to Russia for refining.

In mid-December, press reports stated

that Zaire's Shaba Province, where the country's copper-cobalt industry is located, reverted to its former name Katanga and declared autonomy from the rest of the country. The Province reportedly planned to impose taxes on imports and exports to generate revenue. The Zairian Government did not give an official response to the declaration.

Zambia.—In 1993, Zambia replaced Zaire as the world's largest cobalt producer. ZCCM produced 4,211 tons of cobalt metal between January and December 1993, a 9% decrease from the 4,610 tons produced in calendar year 1992.[25] In addition to refining cobalt concentrates from its mining and milling operations, ZCCM has been treating high-cobalt content smelter slags since July 1992. To improve cobalt quality, ZCCM made the following plant modifications: ion exchange columns were installed at the Nkana refinery to reduce nickel levels, and solvent extraction circuits were installed at both the Nkana and Chambishi refineries to reduce zinc levels. In addition, ZCCM planned to increase the installed capacity at its Nkana refinery from 2,500 tons of cobalt per year to 3,000 tons per year during the financial year beginning April 1, 1994.

ZCCM outlined a major mining project intended to maintain current production levels for the next 25 years or more.[26] The Konkola Deep Mining Project would replace production from the Nchanga open pit. Nchanga currently accounts for about 30% of ZCCM's copper production, but it is expected to be mined out by the year 2001. The Konkola project would involve the sinking of a new shaft system and building a new concentrator. At a mining rate of 6 million tons of ore per year, average annual production would be 180,000 tons of finished copper metal and 600 tons of finished cobalt. The total capital cost of the project was estimated at $545 million in 1991 dollars. Once started, the project was expected to take 6 years to complete.

The Zambian Government commissioned a firm of international consultants to study various options and make recommendations on privatizing ZCCM.

Zimbabwe.—Minor amounts of impure cobalt hydroxide were produced in Zimbabwe as a byproduct of nickel mining and refining. The cobalt hydroxide was exported to be refined. *(See tables 12 and 13.)*

Current Research

The USBM researched methods for recycling magnet scrap. The research included a study of mixed grinding swarf generated during magnet fabrication. The grinding swarf was composed of neodymium-iron-boron and samarium-cobalt alloys, cooling and lubricating oils, and grinding media such as silicon carbide. Variations on three metal-recovery methods were investigated: a single-stage sulfuric acid leach, a two-stage sulfuric acid leach, and a simultaneous flotation-leach process. In the simultaneous flotation-leach process, the neodymium-iron-boron leached and remained in solution while the samarium-cobalt concentrated in the froth and the grinding media concentrated in the tails.[27]

The CDI of Wickford, Essex, United Kingdom, published abstracts on cobalt research, articles on selected cobalt uses, and annual and semiannual data on cobalt production by institute members in quarterly issues of Cobalt News. In September, the CDI held a conference on cobalt supply, chemical and metallurgical uses, occupational and environmental exposure, and legislation.[28]

OUTLOOK

Total world cobalt production continued to decline in 1993. This was primarily because of the ongoing decrease in production by Zaire, which has led to several changes in the cobalt market. Political and economic conditions in Zaire were not resolved, and production was not anticipated to return to former levels in the near term.

Cobalt refiners, processors, and consumers have reevaluated their feed material requirements and, where possible, have been making adjustments to their processes to accommodate a wider range of cobalt materials. Several existing cobalt refiners have increased their capacities, and plans are underway for new refiners to begin production in Canada and Uganda. Belgian production of cobalt from residues generated by the zinc industry also would be considered new production. In terms of quantity, these increases in production will not equal the loss of production from Zaire. In addition, the products made—electrolytic cobalt, metal powders, or chemicals—will determine how the increased production will influence the cobalt market.

Cobalt demand is expected to increase as the economies of the major consuming countries improve. Of particular importance to the cobalt market is the outlook for the aerospace industry because of the quantities and quality of cobalt required to make jet engine parts. Although there may be adequate quantities of cobalt available when demand improves, the question remains whether there will be a shortage of high-quality cobalt. One analyst estimated that in addition to high-quality cobalt from other producers, 1,000 to 2,000 tons of electrolytic cobalt would be required annually from Zaire to satisfy market demand during the next 2 to 3 years.[29] Of the new refiners expected to begin production, only Uganda currently plans to produce electrolytic cobalt. At an anticipated rate of 1,000 tons per year, Ugandan cobalt could help ease, but may not eliminate, a potential shortfall in high-quality cobalt metal. Upgrading lower quality cobalt to higher quality cobalt may become an economically viable solution.

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TABLE 1
WORLD PRODUCERS OF REFINED COBALT IN 1993

Country	Company	Cobalt products
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
Do.	Sherritt Inc.	Metal powder, briquettes.
China	China National Nonferrous Metals Industry Corp.	Cathode,[1] oxide, salts.
Finland	OM Group, Inc.	Metal powder, oxide, salts.
France	Eramet-SLN	Chloride.
Japan	Sumitomo Metal Mining Co. Ltd.	Cathode, oxide, salts.
Norway	Falconbridge Ltd.	Cathode.
Russia	Norilsk Nickel Complex	Ingot, cathode, oxide, salts.
Do.	Yuzhural Nickel Complex	
South Africa, Republic of	Impala Platinum Ltd.	Metal powder.
Do.	Rustenberg Base Metal Refiners Pty. Ltd.	Sulfate.
Zaire	La Générale des Carrières et des Mines.	Cathode, granules.
Zambia	Zambia Consolidated Copper Mines Ltd.	Cathode, crushed bar.

[1]Other metal forms possible.

TABLE 2
WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS[1] IN 1993

Country	Company	Cobalt-containing products
Australia	QNI Ltd.	Cobalt sulfide.
Do.	Western Mining Corp.	Nickel-cobalt sulfide, nickel matte.
Do.	Pacific Smelting and Mining Co. Ltd.	Impure cobalt oxide.
Botswana	BCL Ltd.	Nickel-copper matte.
Cuba	Unión de Empresas del Níquel	Nickel-cobalt sulfide.
Morocco	Compagnie de Tifnout Tiranimine	Cobalt concentrate.
New Caledonia	Société Metallurgique le Nickel	Nickel matte.
South Africa, Republic of	Western Platinum Ltd.	Nickel sulfate, nickel matte.
Zimbabwe	Bindura Nickel Corp. Ltd.	Cobalt-nickel hydroxide.
Do.	Rio Tinto (Zimbabwe) Ltd.	Do.

[1]Excludes companies producing refined cobalt.

TABLE 3
SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Consumption:					
Reported	7,172	7,512	7,240	r6,471	6,473
Apparent	7,164	7,635	7,786	6,526	7,305
Imports for consumption	5,793	6,529	6,924	5,757	5,945
Exports	889	1,340	1,536	1,424	795
Stocks, December 31[1]	1,456	1,853	1,622	r896	875
Price: Metal, per pound[2]	$7.64	$10.09	$16.92	$22.93	$13.79
World: Production					
Mine	r42,873	r42,420	r32,906	r27,131	e22,224
Refinery	r26,407	r27,297	r24,761	r21,901	e16,893

eEstimated. rRevised.
[1]Stocks held by consumers and chemical processors.
[2]Market price based on weighted average of Metals Week's prices.

TABLE 4
U.S. REPORTED CONSUMPTION OF COBALT,[1] BY END USE

(Metric tons, cobalt content)

End use	1989	1990	1991	1992	1993
Steel:					
Full-alloy	W	W	W	W	W
Stainless and heat-resisting	74	41	51	26	41
Tool	219	123	W	47	59
Superalloys	2,860	3,345	3,066	2,697	2,614
Alloys (excluding alloy steels and superalloys):					
Cutting and wear-resistant materials[2]	538	541	525	522	569
Magnetic alloys	870	710	713	670	629
Nonferrous alloys	27	31	32	W	(3)
Welding materials (structural and hard-facing)[4]	136	180	135	r128	171
Other alloys	52	74	62	45	595
Mill products made from metal powder	W	W	W	W	W
Chemical and ceramic uses:					
Catalysts	W	W	W	949	935
Drier in paint or related usage	718	6751	6781	6745	6732
Ground coat frit	366	357	W	257	W
Pigments	W	W	W	197	193
Miscellaneous and unspecified[7]	1,313	1,361	1,876	187	433
Total[8]	7,172	7,512	7,240	r6,471	6,473

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes estimates.
[2]Includes diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.
[3]Included with "Other alloys."
[4]Includes wear-resistant alloys.
[5]Includes "Nonferrous alloys."
[6]Data not comparable with 1989 because of a change in reporting method.
[7]Includes feed or nutritive additive, glass decolorizer, and data indicated by symbol "W."
[8]Data may not add to totals shown because of independent rounding.

TABLE 5
U.S. REPORTED CONSUMPTION OF COBALT,[1] BY FORM

(Metric tons, cobalt content)

	1989	1990	1991	1992	1993
Chemical compounds (organic and inorganic)[2]	2,081	2,192	2,137	2,105	2,043
Metal	3,907	4,095	3,525	r2,753	2,864
Purchased scrap	1,184	1,225	1,578	1,613	1,566
Total	7,172	7,512	7,240	r6,471	6,473

rRevised.
[1]Includes estimates.
[2]Includes oxides.

TABLE 6
U.S. REPORTED STOCKS OF COBALT MATERIALS,[1] DECEMBER 31

(Metric tons, cobalt content)

	1989	1990	1991	1992	1993
Chemical compounds (organic and inorganic)[2]	394	379	362	344	307
Metal	860	1,342	1,072	r399	410
Scrap	202	132	189	153	158
Total	1,456	1,853	[3]1,622	r896	875

rRevised.
[1]Stocks reported by cobalt processors and consumers; includes estimates.
[2]Includes oxide.
[3]Data do not add to total shown because of independent rounding.

TABLE 7
YEAREND PRICES OF COBALT MATERIALS[1]

(Dollars per pound)

Material	1989	1990	1991	1992	1993
Cobalt metal:					
Cathode or granules (shot)[2 3]	8.40	8.40	11.00	[4]18.00	18.00
Fine powder (less than 1.6 micrometers)[5]	17.75	22.11	31.67	32.11	NA
Powder (300-mesh, 400-mesh, 100-mesh)	14.71	18.63	29.46	29.10	NA
S-grade powder (minus 48-mesh)	[6]8.65	[6]8.65	[7]11.90	XX	XX
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	9.42	11.14	18.94	18.00	NA
Ceramic-grade (72% to 73% cobalt)	9.67	11.44	19.44	18.50	NA
Metallurgical-grade (76% cobalt)	10.06	11.67	19.69	NA	NA

NA Not available. XX Not applicable.
[1]Prices are list prices from African Metals Corp., unless otherwise noted.
[2]See table 3 for cathode market price.
[3]250-kilogram drums.
[4]Cathode price. Yearend price for granules was $17.00 per pound.
[5]50-kilogram drums.
[6]Sherritt Gordon Ltd. list price.
[7]Metals Week.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

		1991	1992	1993
Metal:[1]				
Gross weight		6,375	5,274	5,388
Cobalt content[2]		6,375	5,274	5,388
Value	thousands	$157,711	$246,393	$166,284
Oxides and hydroxides:				
Gross weight		583	431	444
Cobalt content[2]		420	310	320
Value	thousands	$12,941	$18,651	$12,612
Other forms:				
Acetates:				
Gross weight		33	92	13
Cobalt content[2]		8	22	3
Value	thousands	$309	$646	$141
Carbonates:				
Gross weight		53	34	57
Cobalt content[2]		24	16	26
Value	thousands	$776	$934	$980
Chlorides:				
Gross weight		12	42	17
Cobalt content[2]		3	11	4
Value	thousands	$101	$651	$157
Sulfates:				
Gross weight		350	461	754
Cobalt content[2]		95	125	204
Value	thousands	$2,295	$5,548	$6,037
Total:[3]				
Gross weight		7,406	6,334	6,674
Cobalt content[2]		6,924	5,757	5,945
Value	thousands	$174,134	$272,822	$186,211

[1]Unwrought cobalt, excluding alloys and waste and scrap.
[2]Estimated from gross weights.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY

Country of origin	Metal[1]			Oxides and hydroxides			Other forms[2]			Total[3]		
	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)
1992:												
Belgium	345	345	$19,108	150	108	$6,857	50	13	$735	545	465	$26,701
Brazil	8	8	385	—	—	—	2	1	30	10	9	415
Canada	875	875	40,461	2	1	72	16	7	479	892	883	41,013
China	50	50	1,727	11	8	434	—	—	—	61	57	2,161
Finland	223	223	14,141	145	104	5,970	385	104	5,091	753	431	25,202
France	24	24	1,666	7	5	615	—	—	—	31	29	2,281
Germany	86	86	6,200	6	4	238	—	—	—	91	90	6,438
Japan	7	7	382	6	4	145	(5)	(5)	4	13	11	532
Norway	933	933	44,660	—	—	—	—	—	—	933	933	44,660
Russia[6]	431	431	14,698	11	8	444	—	—	—	443	439	15,142
South Africa, Republic of	93	93	4,523	—	—	—	170	46	1,296	263	139	5,819
United Kingdom	44	44	1,871	94	68	3,861	6	2	142	144	114	5,873
Zaire	592	592	27,932	—	—	—	—	—	—	592	592	27,932
Zambia	1,560	1,560	68,421	—	—	—	—	—	—	1,560	1,560	68,421
Other	3	3	216	(5)	(5)	14	—	—	—	4	4	230
Total[3]	5,274	5,274	246,393	431	310	18,651	629	172	7,778	6,334	5,757	272,822
1993:												
Belgium	109	109	6,289	158	114	5,042	21	7	306	288	230	11,637
Brazil	—	—	—	—	—	—	2	(5)	23	2	(5)	23
Canada	790	790	23,198	20	14	449	13	6	222	823	810	23,868
China	—	—	—	2	1	76	—	—	—	2	1	76
Finland	433	433	16,260	158	114	4,078	784	217	6,595	1,375	764	26,932
France	37	37	3,111	6	4	383	—	—	—	43	41	3,494
Germany	120	120	7,677	—	—	—	(5)	(5)	2	120	120	7,679
Japan	2	2	198	18	13	221	(5)	(5)	5	21	15	423
Norway	1,089	1,089	32,474	—	—	—	—	—	—	1,089	1,089	32,474
Russia	539	539	14,505	4	3	82	20	6	141	562	548	14,727
South Africa, Republic of	41	41	1,265	—	—	—	—	—	—	41	41	1,265
United Kingdom	24	24	738	77	56	2,282	3	1	22	104	80	3,042
Zaire	627	627	21,399	—	—	—	—	—	—	627	627	21,399
Zambia	1,556	1,556	38,458	—	—	—	—	—	—	1,556	1,556	38,458
Other	22	22	712	—	—	—	—	—	—	22	22	712
Total[3]	5,388	5,388	166,284	444	320	12,612	842	237	7,315	6,674	5,945	186,211

[1]Unwrought cobalt, excluding alloys and waste and scrap.
[2]Cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates.
[3]Data may not add to totals shown because of independent rounding.
[4]Estimated from gross weights.
[5]Less than 1/2 unit.
[6]Formerly part of the U.S.S.R. Includes materials imported during 1992 under the country code for the U.S.S.R.

Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 10

U.S. EXPORTS OF COBALT IN 1993, BY COUNTRY[1]

Country of destination	Metal[2]		Oxides and hydroxides		Acetates		Chlorides		Total content[4] (metric tons)	Total value[3] (thousands)
	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)		
Argentina	11	$336	26	$386	—	—	—	—	29	$722
Australia	7	172	7	163	(5)	$13	—	—	12	347
Brazil	48	781	15	326	52	504	3	$24	73	1,635
Canada	145	2,711	27	692	3	29	272	1,276	233	4,708
Chile	(5)	11	6	154	—	—	—	—	4	165
Colombia	—	—	9	205	—	—	—	—	6	205
El Salvador	—	—	—	—	11	95	—	—	3	95
France	28	482	1	44	—	—	1	21	29	546
Germany	25	1,102	1	47	—	—	—	—	26	1,149
Hong Kong	6	185	23	417	—	—	—	—	23	602
India	2	30	—	—	14	148	—	—	5	178
Indonesia	38	1,471	—	—	—	—	—	—	38	1,471
Japan	46	879	32	814	—	—	—	—	69	1,693
Korea, Republic of	4	158	1	37	—	—	1	5	5	200
Mexico	4	169	106	1,557	76	579	1	15	98	2,320
Netherlands	7	395	5	102	1	7	—	—	11	504
Peru	1	14	6	163	—	—	—	—	5	177
Taiwan	(5)	17	30	594	100	1,074	13	188	49	1,874
Turkey	(5)	7	—	—	5	33	—	—	1	40
United Kingdom	45	1,190	—	—	7	35	—	—	46	1,225
Other	17	819	14	381	4	49	—	—	28	1,249
Total[6]	435	10,928	308	6,081	272	2,566	291	1,530	795	21,104

[1]In addition to the materials listed, the United States exported cobalt ores and concentrates and wrought cobalt and cobalt articles.
[2]Includes unwrought cobalt, powders, waste and scrap, and mattes and other intermediate products of cobalt metallurgy.
[3]Free alongside ship (f.a.s.) value.
[4]Estimated from gross weights.
[5]Less than 1/2 unit.
[6]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
WORLD ANNUAL COBALT PRODUCTION CAPACITY, DECEMBER 31, 1993

(Metric tons, cobalt content)

Country	Refinery capacity
Brazil	300
Canada[1]	3,400
China[e]	500
Finland[e 2]	3,000
France[3]	600
Japan[2 4]	2,800
Norway	2,600
Russia[e]	8,000
South Africa, Republic of[2]	750
United States[5]	900
Zaire	18,000
Zambia	5,000
Total	45,850

[e]Estimated.
[1]Includes oxide.
[2]Includes salts.
[3]Cobalt chloride.
[4]Includes an estimated standby capacity of 1,900 metric tons.
[5]Standby capacity.

TABLE 12
COBALT: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons, cobalt content)

Country[2]	1989	1990	1991	1992	1993[e]
Albania[e 3]	600	600	600	[r]20	10
Australia[e 4]	1,100	[r]1,200	[r]1,400	[r]1,600	1,700
Botswana[5]	215	205	208	[r]208	200
Brazil[e]	300	400	400	400	400
Canada[6]	[r]6,167	[r]5,470	[r]5,274	[r]5,102	[7]5,738
Cuba[e 8]	[7]1,825	1,600	1,600	1,500	1,500
Morocco[9]	121	194	325	[r]461	[7]397
New Caledonia[e 10]	800	800	800	800	800
Russia[e 11]	—	—	—	[r]4,000	3,300
South Africa, Republic of[e]	300	350	300	350	350
U.S.S.R.[e 11 12]	[r]5,700	[r]5,500	[r]5,000	—	—
Zaire[9 13]	18,400	19,000	9,900	5,700	2,459
Zambia[9 14]	7,255	6,999	6,994	[r]6,910	5,300
Zimbabwe[e 15]	90	102	105	[r]80	70
Total	[r]42,873	[r]42,420	[r]32,906	[r]27,131	22,224

[e]Estimated. [r]Revised.
[1]Table includes data available through July 11, 1994. 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.
[2]In addition to the countries listed, Bulgaria, China, Germany, Indonesia, 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.
[3]Calculated from reported and estimated weight of nickeliferous ore.
[4]Figures represent cobalt contained in intermediate metallurgical products (cobalt oxide, cobalt sulfide and nickel-cobalt sulfide) 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: 1989—2,268 (revised); 1990—1,870 (revised); 1991—1,670 (revised); 1992—1,270 (revised); and 1993—1,270.
[5]Reported cobalt content of pelletized nickel-copper matte.
[6]Figures represent the assay content of cobalt in concentrates produced. The cobalt content of all products derived from ores of Canadian origin, including cobalt oxide shipped to the United Kingdom for further processing and nickel-copper-cobalt matte shipped to Norway for refining, was reported as follows, in metric tons: 1989—2,344; 1990—2,184; 1991—2,171; 1992—2,223 (revised); 1993—2,370.
[7]Reported figure.
[8]Determined from reported nickel-cobalt content of granular and powder oxide, oxide sinter, and sulfide production.
[9]Cobalt content of concentrates.
[10]Series represents estimated recoverable content of ores and intermediate metallurgical products exported from New Caledonia to France. The estimated cobalt content of total ores mined is as follows, in metric tons: 1989—6,000; 1990—6,000; 1991—6,000; 1992—6,000; and 1993—6,000.
[11]All production in the U.S.S.R. from 1989-91 came from Russia.
[12]Dissolved in Dec. 1991.
[13]In addition to concentrates, cobalt hydrates and scrap are used as feed to the refineries. Cobalt content of these materials was as follows, in metric tons: Hydrates: 1989—0; 1990—3,194; 1991—5,483; 1992—4,106; and 1993—not available. Scrap: 1989—27; 1990—49; 1991—517; 1992—1,113; and 1993—not available.
[14]Fiscal years beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1989—10,590; 1990—10,870; 1991—10,976; 1992—11,366; and 1993—8,700 (estimated).
[15]Estimated cobalt content of ore.

TABLE 13

COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons, cobalt content)

Country[2]	1989	1990	1991	1992	1993[e]
Albania: Oxide[e]	10	20	r15	r3	1
Brazil: Metal[e]	70	240	240	240	240
Canada: Metal (including metal powder and oxide)	2,110	2,063	2,248	2,210	2,695
China: Metal[e]	r255	325	r300	r220	300
Finland:					
Metal (including metal powder)[e]	292	330	270	230	300
Salts[e]	1,003	970	1,233	1,870	1,900
Total	1,295	1,300	1,503	2,100	[3]2,200
France: Chloride	165	150	r123	e150	150
Japan: Metal	99	199	185	105	190
Norway: Metal	1,946	1,830	1,983	2,293	[3]2,414
Russia: Unspecified[e 4]	—	—	—	r4,500	4,000
South Africa, Republic of:					
Metal (powder)[e]	60	70	60	65	50
Sulfate[e]	139	179	149	169	122
Total	199	249	209	234	[3]172
U.S.S.R.: Unspecified[e 4 5]	r6,500	r6,300	r5,100	—	—
Zaire: Metal[6]	9,311	9,947	8,114	5,049	[3]831
Zambia: Metal[7]	4,447	4,674	4,741	r4,797	3,700
Total	r26,407	r27,297	r24,761	r21,901	16,893
Of which:					
Metal	r18,590	r19,678	r18,141	r15,209	10,720
Salts[8]	1,317	1,319	r1,520	r2,192	2,173
Unspecified	r6,500	r6,300	r5,100	r4,500	4,000

[e]Estimated. [r]Revised.

[1]Table includes data available through July 11, 1994. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

[2]In addition to the countries listed, Belgium, Czechoslovakia, and Germany may recover cobalt from imported materials, but production is not reported, and information is inadequate to make reliable estimates of production.

[3]Reported figure.

[4]All production in the U.S.S.R. from 1988-91 came from Russia.

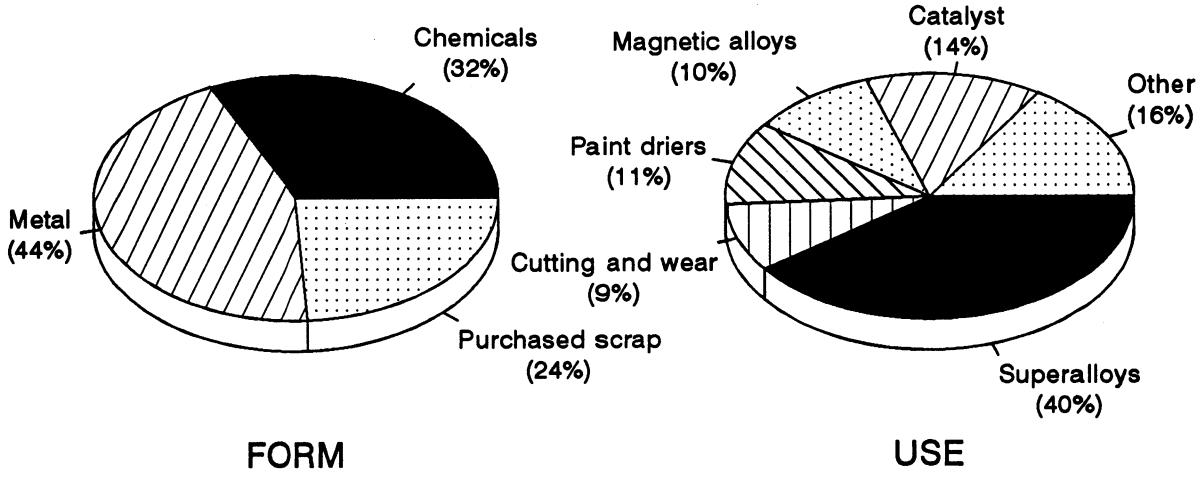
[5]Dissolved in Dec. 1991.

[6]Excludes production of cobalt in white alloy, matte, and slag that would require further refining.

[7]Fiscal years beginning Apr. 1 of that stated.

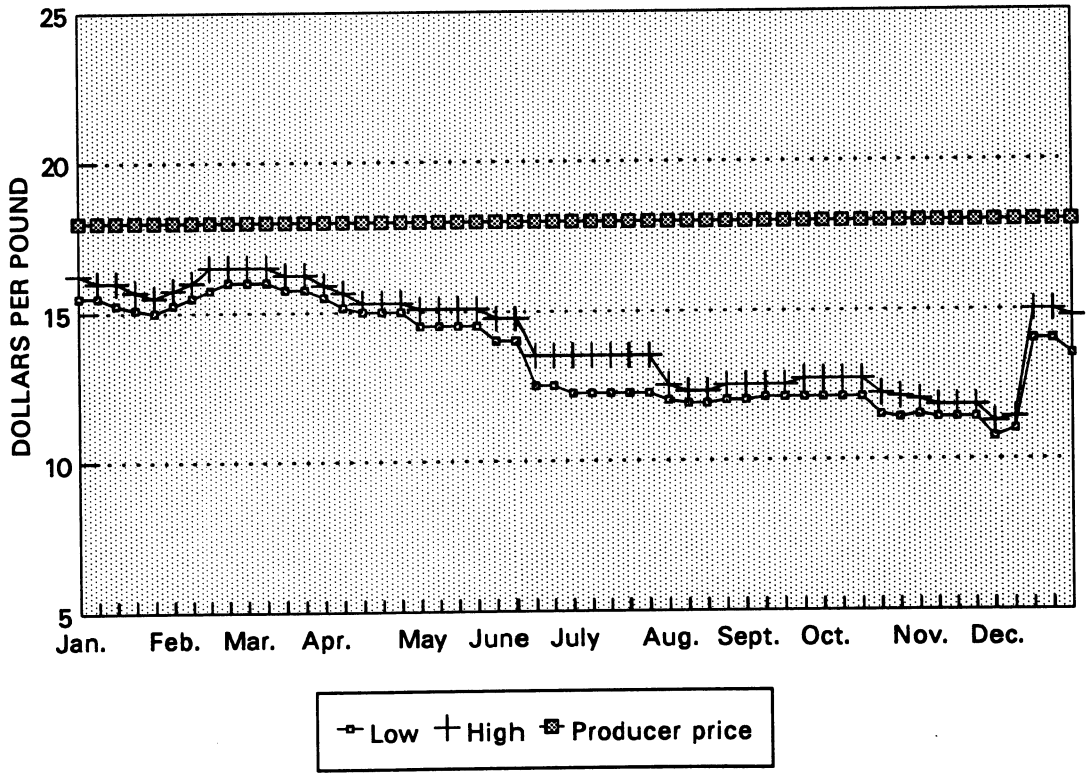
[8]Includes oxide.

FIGURE 1
U.S. COBALT CONSUMPTION IN 1993, BY FORM AND USE



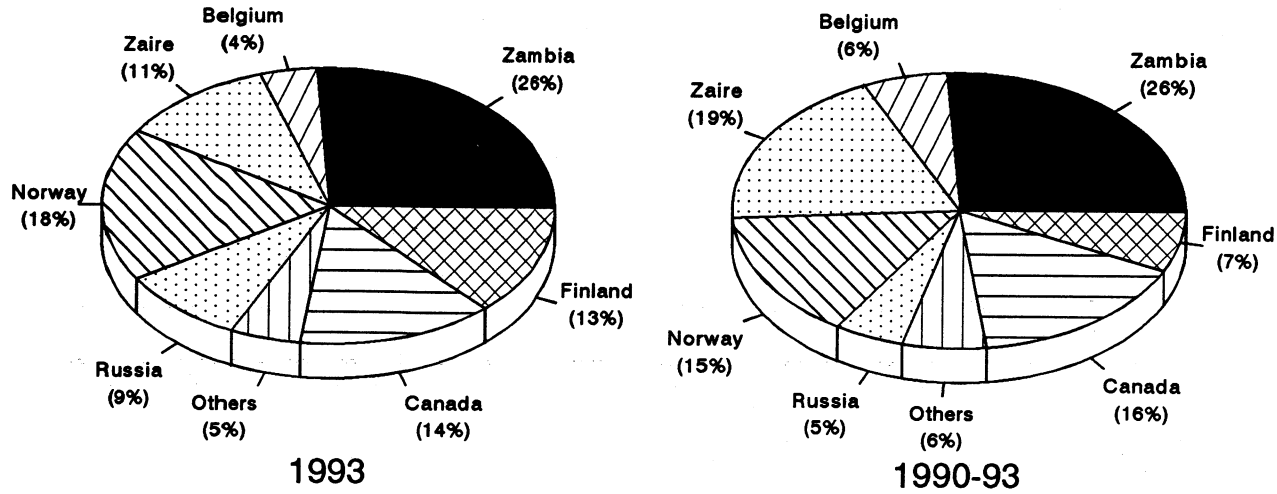
6,473 METRIC TONS

FIGURE 2
TIME-PRICE RELATIONSHIPS FOR COBALT IN 1993



Source: Platt's Metals Week.

FIGURE 3
U.S. COBALT IMPORTS, BY SOURCE



Source: Bureau of the Census.