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Cobalt

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In 2021, cobalt was mined in the United States as a byproduct of nickel and copper production in Michigan and recovered from tailings generated by previous mining of lead and other metals in Missouri. Cobalt also was recovered in negligible amounts as an intermediate nickel compound from the mining and refining of platinum-group-metal (PGM) ore in Montana. The total quantity of U.S. cobalt mine production was an estimated 650 metric tons (t), an 8% increase from that in 2020 (table 1).

In 2021, world production of mined cobalt increased by 12% to 164,000 t owing primarily to increased production in Congo (Kinshasa), where an idled operation restarted production, a new operation began production, and most of the other operations increased production. Congo (Kinshasa) remained the leading producer of mined cobalt, supplying 73% of world production (tables 1, 7).

The United States did not refine cobalt ores or concentrates in 2021. World production of refined cobalt was 148,000 t, essentially unchanged from 147,000 t (revised) in 2020. China remained the leading producer of refined cobalt, supplying 74% of the world total. In 2021, world production of refined cobalt chemicals (including fine metal powder) increased compared with production in 2020 and world production of refined cobalt metal (including coarse metal powder) decreased compared with that in 2020 (tables 1, 8; Darton Commodities Ltd., 2023, p. 16).

In 2021, U.S. apparent consumption of cobalt decreased by 22% from that in 2020, a result of decreases in net imports and secondary production (which was estimated from scrap consumption) (tables 1, 2). Globally, world consumption of refined cobalt increased in 2021 from that in 2020 owing largely to an increase in cobalt use in rechargeable batteries for electric vehicles. All other end use sectors also experienced growth in 2021 with varying degrees of recovery from the effects of the global coronavirus disease 2019 (COVID-19) pandemic. Cobalt supply-demand scenarios by multiple analysts showed the market being in a deficit at yearend 2021 (Holman, 2021; Cobalt Institute, 2022, p. 7–10, 20–22, 42; Darton Commodities Ltd., 2022, p. 27, 53).

Cobalt is a metallic element used in numerous diverse commercial, industrial, and military applications. Globally, beginning in 2021, the leading use of cobalt was lithium-ion batteries for electric vehicles. The second-ranked use was other lithium-ion battery applications such as drones, energy storage, laptops and tablets, and mobile phones. The third-ranked use was superalloys, which were used to make parts for gas turbine engines and other products requiring high strength and surface stability at elevated temperatures. Other metallurgical uses for cobalt included cemented carbides (also called hardmetals) and diamond tools, controlled-expansion and corrosion- and wear-resistant alloys, high-speed and maraging steels, and magnets. Other chemical uses for cobalt included animal feed additives; catalysts in the chemical and petroleum industries; drying agents for inks, paints, and varnishes; dyes and pigments; glass decolorizers; ground coats for porcelain enamels; humidity indicators; magnetic recording media; rubber adhesion promoters for steel-belted radial tires; and as a component of vitamin B12 (Cobalt Institute, 2022, p. 4, 9, 19–20).

Government Actions and Legislation

Critical Minerals.—Critical minerals are defined as nonfuel minerals or mineral materials essential to the economic and national security of the United States, the supply chains of which are vulnerable to disruption, and that serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the U.S. economy or national security. In 2021, the U.S. Geological Survey (USGS) updated its methodology for assessing mineral criticality to include a quantitative ranking of commodities and released a draft list of critical minerals. Cobalt was included in the draft list and ranked third in terms of supply chain risk from highest to lowest out of 50 commodities. Cobalt was also included in the original unranked list of 35 critical minerals published in 2018 (Trump, 2017; Fortier and others, 2018; Nassar and Fortier, 2021, p. 1–7, 10, 12–14, 16; U.S. Geological Survey, 2021).

In February, the President signed Executive Order 14017 "America's Supply Chains" directing a review of vulnerabilities in and strengthening the resilience of critical supply chains. The final report as well as actions the administration would take to strengthen supply chain resilience were announced in June. The report emphasized the need to invest in the electric vehicle battery supply chain from material sourcing through end-of-life collection and recycling of battery materials such as cobalt, graphite, and lithium. The report emphasized the need to work with allies and partners to diversify foreign supply chains and to invest in sustainable domestic production, refining, and recycling of critical minerals and materials. The U.S. Department of Defense was directed to deploy Defense Production Act title III incentives to support sustainably produced strategic and critical minerals, and the U.S. Department of Energy Loan Programs Office was directed to leverage existing funds to support critical materials mining, extraction, processing, recovery, or recycling technologies. As part of a longer term strategy outlined in the report, cobalt was specifically mentioned in recommendations to elevate sustainability standards for critical mineral production domestically and abroad (Biden, 2021; White House, The, 2021).

In April, the U.S. Department of Energy's Critical Materials Institute awarded funding to Electra Battery Materials Corp. (formerly First Cobalt Corp.) (Canada) for research on mineral processing technologies for its Iron Creek copper-cobalt project. The Iron Creek project is within the historic Blackbird cobalt-copper district of the Idaho cobalt belt, southwest of Salmon in Lemhi County, ID. The objective of the research, which would be in conjunction with the Kroll Institute for Extractive

Metallurgy at the Colorado School of Mines, was to identify more efficient and environmentally friendly methods for recovering cobalt from pyrite ore (First Cobalt Corp., 2021).

In June, the Federal Consortium for Advanced Batteries, led by the Energy, Defense, Commerce, and State Departments and including other Government organizations, released a national blueprint for lithium batteries. The report outlined goals and steps to establish a secure, domestic supply chain for lithium-based batteries and battery materials, like cobalt, by 2030. Key objectives included increasing U.S. production capacity for battery materials, recycling and recovery of critical metals and materials, and ultimately eliminating scarce materials like cobalt from lithium batteries by 2030 (U.S. Department of Energy, 2021, p. 5–6, 18–22).

The Infrastructure Investment and Jobs Act (H.R. 3684) became Public Law 117–58 on November 15, 2021. This law included multiple provisions supporting critical mineral research and domestic production and processing, which included cobalt. These provisions included the USGS' Earth Mapping Resource Initiative and prioritized mapping and assessing critical mineral deposits (section 40201); measures to improve the timeliness of Federal permitting for critical mineral production (section 40206); grant programs for battery material processing and recycling to strengthen the domestic battery supply chain (section 40207); the electric drive vehicle battery recycling and second-life applications program to encourage recycling and reuse of electric vehicle batteries (section 40208); and a grant program for research to advance critical mineral mining, recycling, and reclamation (section 40210) (U.S. Congress, 2021, p. 958–959, 961–975, 978–983).

National Defense Stockpile.—The Defense Logistics Agency Strategic Materials (DLA Strategic Materials), U.S. Department of Defense, did not sell or ship cobalt in 2021. During the calendar year, the DLA Strategic Materials acquired 3 t (gross weight) of cobalt alloys. Calendar yearend National Defense Stockpile (NDS) inventories of cobalt materials are listed in table 1.

Production

In 2021, three companies produced cobalt-bearing ore concentrates in the United States. Estimated U.S. mine production increased by 8% to 650 t from that in 2020 (tables 1, 7). Lundin Mining Corp. (Canada) produced copper and nickel sulfide concentrates from its underground Eagle nickel-copper mine, northwest of Marquette, MI, and at its mill in Humboldt Township, MI. Eagle's nickel concentrates, which contained cobalt, were sent by rail to be smelted in Canada (Lundin Mining Corp., 2022, p. 43, 46–47).

Missouri Cobalt, LLC produced a bulk concentrate containing cobalt, copper, and nickel by reprocessing tailings from previous mining of lead and other metals at the Madison Mine near Fredericktown, MO. In 2021, the company continued construction of a commercial-scale hydrometallurgical plant in Fredericktown that would produce battery-grade cobalt sulfate and nickel sulfate. The plant was designed to process concentrates produced from mined ore and tailings from the Madison Mine, shredded lithium-ion battery scrap, and feed from other companies (PRNewswire, 2021; M.R. Hollomon II, Chief Executive Officer, Missouri Cobalt, LLC, written commun., January 24, 2022).

Sibanye Stillwater Ltd. (South Africa) produced negligible amounts of cobalt in nickel sulfate at its PGM mining and refining operations in southern Montana. The nickel sulfate was sold to other companies (Stillwater Mining Co., 2017, p. 21).

In 2021, Jervois Global Ltd. (formerly Jervois Mining Ltd.) (Australia) continued construction at its 100%-owned Idaho Cobalt Operations (ICO) project, west of Salmon, ID. Based on the bankable feasibility study released in 2020, the operation would process approximately 1,090 metric tons per day of cobalt-copper-gold ore from an underground mine over a period of 7 years to produce a bulk (multimetallic) concentrate containing 1,915 metric tons per year (t/yr) of cobalt. In 2021, Jervois acquired partial ownership of the Freeport Cobalt business in Kokkola, Finland, and had an agreement to acquire 100% of the São Miguel Paulista nickel-cobalt refinery in Sao Paulo, Brazil. Jervois decided to produce separate cobalt and copper concentrates at the ICO project and to produce cobalt metal at its Brazilian refinery from the ICO project's cobalt concentrate as well as concentrates from other companies. Jervois expected production of concentrates from the ICO project to begin in the quarter ending September 2022. The refinery acquisition was expected to close by the end of April 2022 and first refinery production from the ICO project's cobalt concentrate was expected in the quarter ending September 2023 (Jervois Global Ltd., 2022, p. 13–20, 27–28, 43, 50, 52, 55–56).

During 2021, PolyMet Mining Corp. (Canada) continued to face legal challenges for various permits and approvals granted for its proposed open pit mine at the NorthMet copper-nickel-cobalt sulfide deposit in the Duluth Complex in northeastern Minnesota. PolyMet had received permits in 2018 and 2019 from the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, and the U.S. Army Corps of Engineers. At yearend 2021, the Permit to Mine; National Pollutant Discharge Elimination System and State Disposal System water discharge permit; and the Clean Water Act section 404 permit, which regulates the discharge of dredged or fill material into U.S. waters; were pending resolution of ongoing litigation. All three permits were required for project construction and operation. These challenges delayed PolyMet's plan to construct and operate the open pit mine at the NorthMet site. The mine was expected to produce a copper concentrate and a nickel concentrate containing about 140 t/yr of cobalt. The company continued to discuss debt and equity financing to fund permit litigation, project optimization, and construction. PolyMet forecast that construction and rampup to commercial production would take approximately 30 months after receiving funding (PolyMet Mining Corp., 2022, p. 4–6, 25–27, 34).

U.S. processors produced intermediate or marketable cobalt chemicals from refined cobalt materials and (or) cobalt-bearing scrap. USGS data on chemical and metal powder production, shipments, and stocks were derived from a monthly voluntary survey of U.S. cobalt processors. Approximately six companies in the United States produced cobalt chemicals. Information from this survey was used to prepare the statistics on cobalt consumption and stocks in tables 1 and 2.

Cobalt was recovered from secondary (scrap) materials by a subsidiary of Plansee Group (Austria). Plansee's Global Tungsten & Powders Corp. (GTP) plant in Towanda, PA, recovered an intermediate cobalt chemical compound as a byproduct of tungsten recovery from cemented carbide scrap. GTP had a long-term agreement with Umicore N.V./S.A. (Belgium) whereby Umicore would toll process GTP's intermediate cobalt compound to cobalt metal powder (Global Tungsten & Powders Corp., 2014).

Consumption

U.S. estimated consumption of cobalt in 2021 was essentially unchanged from that in 2020 (tables 1, 2). Cobalt consumption by metallurgical industries was estimated to have increased by 6%, and cobalt consumption by chemical industries was estimated to have decreased by 10% from that in 2020. Estimated consumption statistics were derived by the USGS from voluntary surveys of U.S. operations. Most of the cobalt chemical-use data were obtained from the cobalt processors survey. A second survey covered a broad range of metal-consuming companies, such as cemented carbide, magnetic alloy, and superalloy producers. For this survey, about 50 cobalt consumers were canvassed on a monthly or annual basis. Consumption and stocks data in tables 1 and 2 include estimates based on prior reports or industry trends to account for nonrespondents.

U.S. apparent consumption for 2021, as calculated from net imports, consumption from purchased scrap, and changes in Government and industry stocks, decreased by 22% from apparent consumption in 2020 (table 1). The decrease was a result of lower net imports and decreased consumption from scrap (tables 1, 2). Discrepancies in volumes or trends between reported and apparent consumption can result for several reasons, including consumers missing from USGS surveys, the degree of uncertainty in consumption and stock estimates for nonresponding consumers to the surveys, and any misclassified trade data.

Prices

The annual average U.S. spot price for electrolytic cobalt (cobalt cathode, minimum of 99.8% cobalt), as reported by S&P Global Platts Metals Week, was $24.21 per pound; 54% more than that in 2020 (table 1). During the year, the weekly spot price generally trended upward; the lowest price was $16.00 to $16.50 per pound in early January, and the highest price was $33.00 to $33.90 per pound in late December.

Cobalt metal with a minimum of 99.8% cobalt in the form of briquets (known as briquettes by the cobalt industry), broken and cut cathode, coarse metal powder, and rounds was traded under a physically settled futures contract on the London Metal Exchange Ltd. (LME). This physically settled contract provided for the delivery of physical metal at the agreed time in the future. Sherritt International Corp. (2022, p. 15) noted that companies preferred the Fastmarkets Metal Bulletin (Fastmarkets MB) standard-grade cobalt price for the negotiation and settlement of contracts. During the year, the monthly LME cash mean price increased from a low of $17.10 per pound in January to a high of $31.26 per pound in December. The annual average mean of cash buyer and cash seller prices and yearend LME inventory levels are listed in table 1.

The Chicago Mercantile Exchange (CME Group) offered a cash-settled cobalt futures contract on Commodity Exchange, Inc. (known as the COMEX exchange); the contract was launched in late 2020. In contrast to a physically settled contract, which provided for delivery of physical metal, this cash-settled contract provided for the transfer of the cash value of the physical metal based on a reported price for standard-grade cobalt from Fastmarkets MB. In 2021, 3,297 t of cobalt was traded on the CME Group's cash-settled futures contract. The LME also offered a cash-settled futures contract indexed to the Fastmarkets MB price for standard-grade cobalt, in addition to its physically settled contract. There were no trades on the LME cash-settled contract in 2021 (Spilker, 2021; Desai, 2022; Darton Commodities Ltd., 2023, p. 65; London Metal Exchange Ltd., undated).

Cobalt metal contracts also were offered on the China Stainless Steel Exchange, based in Wuxi, Jiangsu Province, and the Ganzhou Rare Metal Exchange. In late 2021, it was announced that the Ganzhou Rare Metal Exchange would be merged into a new company composed of China Minmetals Rare Earth Co., Ltd., Chinalco Rare Earth & Metals Co., Ltd., China Southern Rare Earth Group Co., Ltd., and Ganzhou Zhonglan Rare Earth New Material Technology Co., Ltd. (Thomson Reuters, 2020a; Daly, 2021b; Wuxi Stainless Steel Exchange, undated).

Foreign Trade

Net import reliance as a percentage of apparent consumption is one measure of the adequacy of current domestic production to meet demand. Net import reliance is 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 originally imported or produced in the United States. In 2021, net import reliance as a percentage of apparent consumption for cobalt was 73%. Because U.S. cobalt mine production was exported to be refined, this indicated that 73% of U.S. cobalt supply was from imports and stock releases of refined cobalt and 27% was from domestic or imported scrap.

The cobalt content of U.S. imports and exports was estimated based on gross weight data reported by the U.S. Census Bureau and estimated cobalt content. In 2021, U.S. imports of cobalt contained in metal and chemical compounds were 9,800 t, valued at $439 million, essentially unchanged from 9,740 t of cobalt imported in 2020 (table 3). On the basis of cobalt content, seven countries supplied 87% of U.S. imports in 2021. Norway was the leading supplier, followed by Finland, Japan, Canada, Russia, the United Kingdom, and Belgium (table 4). The U.S. Census Bureau also reported U.S. imports, in gross weight, of the following materials: cobalt waste and scrap (1,560 t, valued at $19.8 million), unwrought cobalt alloys (210 t, valued at $9.8 million), and wrought cobalt and cobalt articles (315 t, valued at $45.8 million) (Shedd, 2022).

U.S. exports of unwrought cobalt and cobalt contained in chemicals were 4,930 t, valued at $140 million, 44% more than the 3,430 t (revised) exported in 2020 (table 5). On the basis

of cobalt content, Canada was the leading destination for these exports, followed by Ireland, the United Kingdom, France, and Germany, each of which imported more than 300 t of cobalt from the United States. The U.S. Census Bureau also reported that the United States exported 1,840 t gross weight of wrought metal and cobalt articles valued at $172 million, an increase from 1,380 t gross weight valued at $142 million in 2020, and 2 t gross weight of cobalt ores and concentrates valued at $26 million compared with 150 t gross weight valued at $521 million in 2020 (Shedd, 2022).

World Review

In 2021, world cobalt mine production totaled 164,000 t, an increase of 12% compared with production in 2020 (table 7). The increase was mainly the result of a 21% increase in estimated production in Congo (Kinshasa), the leading global producer of mined cobalt. World cobalt refinery production was essentially unchanged compared with that in 2020. Increases in refinery production of cobalt in China and Madagascar were mostly offset by decreases in most other countries (table 8).

Cobalt was produced as a byproduct of copper, nickel, and other metals, and as a primary product (the principal product of a mining or processing operation). Nonbyproduct (or primary) cobalt production included mine and refinery production in Morocco, artisanal mining of the mineral heterogenite (a trivalent cobalt oxyhydroxide mineral) in Congo (Kinshasa), and recovery of cobalt from previously stockpiled intermediate materials [for example, tailings in Congo (Kinshasa)], which were processed primarily to recover cobalt.

Refinery capacity by country is listed in table 6. Depending on vertical integration and the processes used, these plants consumed mainly ores, concentrates, and (or) partially refined intermediate materials; they also may have consumed some secondary (scrap) materials. The table does not include plants that reprocessed refined cobalt, plants that used scrap as their main source of feed, or plants that produced a partially refined intermediate material that required further refining by another plant.

Australia.—In 2021, Australia was the third-ranked cobalt-producing country or locality in the world in terms of mine output and ranked sixth in terms of refinery output. At least six companies mined cobalt as a byproduct from nickel or nickel-copper ores in the State of Western Australia. Cobalt mine production decreased by 6% from that in 2020. Glencore plc's (Switzerland) Murrin Murrin nickel-cobalt laterite mining and refining operation, operated by Minara Resources Ltd., was Australia's leading producer of mined cobalt and the sole producer of refined cobalt, which was in the form of coarse powder and briquettes. In 2021, Murrin Murrin produced 2,800 t of refined cobalt, 15% less than the 3,300 t produced in 2020. The decrease in production at the nickel-cobalt refinery was attributed to maintenance issues and a statutory shutdown during the year (tables 7, 8; Glencore plc, 2022a, p. 65, 247; undated).

Cobalt also was mined at BHP Group Ltd.'s Nickel West integrated nickel sulfide operation, First Quantum Minerals Ltd.'s (Canada) Ravensthorpe nickel-cobalt laterite mining and acid-leach processing operation, IGO Ltd.'s Nova nickel-copper-cobalt sulfide mine, Panoramic Resources Ltd.'s Savannah nickel-copper-cobalt sulfide mine, and Western Areas Ltd.'s Forrestania nickel sulfide mining operation (BHP Group Ltd., 2022, p. 14; First Quantum Minerals Ltd., 2022, p. 11, 14, 68; IGO Ltd., 2022, p. 3; Panoramic Resources Ltd., 2022, p. 1–4; Western Areas Ltd., 2022, p. 1).

Belgium.—Darton Commodities Ltd. (2022, p. 16) estimated that Umicore's 2021 cobalt production from its Olen refinery was 23% lower than that in 2020 (table 8). The decrease in production was likely the result of Umicore's plan to transfer cobalt refining and some of the cobalt processing activities from Olen to its Kokkola refinery in Finland by mid-2023. The Olen refinery produced a variety of cobalt oxides, salts, and cobalt metal powders. Umicore's production was mainly from intermediate materials sourced from other companies, which included a long-term agreement with Glencore for the supply of crude cobalt hydroxide from Glencore operations in Congo (Kinshasa) to Umicore's refineries in Olen; Ganzhou, Jiangxi Province, China; and Kokkola, Finland (Umicore N.V./S.A., 2019, 2020).

Brazil.—Cobalt was mined as a byproduct of nickel at Atlantic Nickel Mineração Ltda.'s Santa Rita open pit nickel-copper-cobalt sulfide mine and beneficiation plant in Bahia State. In 2021, the operation produced 266 t of cobalt in nickel concentrate, 66% more than the estimated 160 t produced in 2020 (Atlantic Nickel Mineração Ltda., 2022).

Jervois entered into an agreement with Companhia Brasileira de Alumínio in 2020 to acquire the São Miguel Paulista nickel-cobalt refinery in Sao Paulo, which had the capacity to produce 25,000 t/yr of nickel metal and 2,000 t/yr of cobalt metal and was placed on care-and-maintenance status in 2016. The closing date for the acquisition was April 30, 2022. In 2021, Jervois initiated a bankable feasibility study for the refinery restart that included adding pressure oxidation leaching for processing mineral concentrates. Jervois planned to commission the refinery in stages, initially using nickel-cobalt hydroxide (often called mixed hydroxide precipitate or MHP) and crude cobalt hydroxide as feed, followed by processing concentrates from its ICO project and other companies using pressure oxidation leaching. Jervois expected to begin cobalt production from the pressure oxidation autoclave during the quarter ending in June 2023. The initial products would be nickel metal and cobalt metal (Jervois Global Ltd., 2022, p. 13–17, 54–57).

Canada.—In 2021, Canada ranked fourth in global cobalt mine production and third in global cobalt refinery production. Canada's cobalt mine production, which was a byproduct of nickel mining, decreased by 9% from revised production in 2020, and Canada's production of refined cobalt from domestic and imported feeds was essentially unchanged from that in 2020 (tables 7, 8).

Vale S.A. (Brazil) produced 1,768 t (1,582 t in 2020) of cobalt metal at its refinery in Long Harbour, Newfoundland and Labrador Province, and 751 t (878 t in 2020) of cobalt metal at its refinery in Port Colborne, Ontario Province. Most of Vale's refined cobalt was produced from company-owned nickel-sulfide and nickel-copper-sulfide mines in Canada. In 2021, 1,770 t (1,591 t in 2020) of cobalt was from ore mined at Voisey's Bay in northeastern Labrador, 304 t (453 t in 2020) was from ore mined at Sudbury, Ontario Province, and 35 t (60 t in 2020) was from ore mined at Thompson, Manitoba Province (Vale S.A., 2021a, p. 65; 2022, p. 92).

Vale began to transition its Voisey's Bay open pit mine to two underground mines, the Reid Brook and Eastern Deeps Mines, which would extend the life of its Voisey's Bay operation and increase the average annual peak production to an estimated 45,000 t of nickel, 20,000 t of copper, and 2,600 t of cobalt. In June 2021, Vale began producing ore at its Reid Brook Mine. The total mine expansion project was 67% complete by yearend 2021 (Vale S.A., 2021b; 2022, p. 108–109).

Glencore's Integrated Nickel Operations included nickel-copper sulfide mines at Sudbury, Ontario Province, and Raglan, Quebec Province; a smelter at Sudbury, which processed ore concentrates and secondary (scrap) materials; and its Nikkelverk refinery in Norway. Glencore reported that in 2021, 1,100 t of the cobalt refined at Nikkelverk originated from concentrates produced at its Canadian nickel mines, compared with 600 t in 2020. In 2021, Glencore also processed secondary materials, including alloy scrap, battery materials, plating residues, and spent catalysts, containing 1,500 t of cobalt through its Integrated Nickel Operations, compared with approximately 2,000 t in 2020 (Glencore plc, 2021, p. 50; 2022a, p. 65; 2022b, p. 11).

In 2021, The Cobalt Refinery Company Inc. [part of a 50–50 joint venture of Sherritt and General Nickel Co. S.A. (Cuba)] produced 3,526 t of cobalt as metal powder and briquettes at its refinery in Fort Saskatchewan, Alberta Province, a 5% increase from 3,370 t of cobalt produced in 2020. Approximately 93% of the joint venture's cobalt originated from its Cuban mining and processing operation and the remainder was from purchased materials. As a result of a United States embargo on imports of products originating from Cuba, cobalt and nickel produced by Sherritt could not be sold to customers in the United States (U.S. Code, 2010; Sherritt International Corp., 2022, p. 9, 16, 68).

Electra Battery Materials worked towards restarting its cobalt refinery near North Cobalt, Ontario Province, which had been on care-and-maintenance status since 2015. In 2021, Electra began preconstruction activities, including detailed engineering and contract awards for long lead equipment. The company expected to commission the refinery, with a nameplate capacity of 6,500 t/yr of cobalt, during the fourth quarter of 2022. Electra finalized long-term feed supply arrangements with Glencore and IXM S.A. (Switzerland) for crude cobalt hydroxide produced in Congo (Kinshasa) by Kamoto Copper Company S.A. (KCC) and Tenke Fungurume Mining S.A.R.L., respectively, and established a long-term offtake agreement with Stratton Metal Resources Ltd. (United Kingdom) for up to 100% of its future cobalt sulfate production (Electra Battery Materials Corp., 2021; 2022, p. 6–8, 10–11).

China.—China was the world's leading producer and consumer of refined cobalt. In 2021, China's estimated production of refined cobalt increased by 4% from that in 2020 and represented 74% of world production. Most of the production was in the form of cobalt salts and oxides (89%), with the remainder as metal and metal powder (11%). In 2021, 85% of China's consumption of refined cobalt was used to make cathode materials for rechargeable batteries (table 8; Cobalt Institute, 2021, p. 17; Darton Commodities Ltd., 2022, p. 22).

Numerous companies refined and (or) processed cobalt in China. In 2021, the leading producers of refined cobalt were Zhejiang Huayou Cobalt Co., Ltd. (Huayou), Shenzhen GEM High-Tech Co. Ltd. (including subsidiary Jiangsu Cobalt Nickel Metal Co. Ltd.), and Jinchuan Group Co. Ltd., listed in descending order of estimated production. Only a small portion of China's cobalt production originated from domestic sources. Domestic mine production was estimated to represent 1% of China's cobalt raw material supply, recycled scrap was estimated to represent 11%, and imported raw materials, 88%. Most of China's refinery production was from imported intermediate cobalt chemical compounds, the majority of which were sourced from Congo (Kinshasa). In 2021, China imported 1,400 t of cobalt in concentrate, 62% less than that imported in 2020, and 93,700 t of cobalt in intermediate materials produced from copper and nickel operations, a slight increase from that imported in 2020. China's imports of cobalt concentrates have trended downward, and its imports of intermediate products have trended upward as more concentrates produced in Congo (Kinshasa) were processed into intermediate materials prior to export. With regard to refined cobalt, in 2021, China imported 6,377 t of cobalt metal, a 3% increase from that imported in 2020 (Darton Commodities Ltd., 2022, p. 15, 22–23, 25).

Congo (Kinshasa).—Congo (Kinshasa) was the world's leading producer of mined cobalt in 2021, with estimated production increasing by 21% and representing 73% of global production. Most of the country's cobalt mine production was from copper-cobalt ores mined using industrial or mechanized methods. The rest was gathered by tens of thousands of artisanal miners handpicking cobalt-rich ores. Artisanal mining filled the role of a swing producer by increasing production during periods of supply deficits and high prices and decreasing production during periods of oversupply and low prices. Artisanal mining, particularly when not managed by local cooperatives or other types of legal entities, can be associated with negative societal and environmental impacts. In 2021, efforts continued to formalize the artisanal mining sector to promote ethical and sustainable cobalt production. Analyst estimates of 2021 cobalt production by artisanal mining ranged from less than 5,000 t to 14,500 t, accounting for 4% to 12% of the cobalt mined in Congo (Kinshasa) (table 7; Cobalt Institute, 2022, p. 27; undated; Darton Commodities Ltd., 2022, p. 10).

Entreprise Générale du Cobalt (EGC), a subsidiary of state-owned La Générale des Carrières et des Mines SA (Gécamines), was launched officially in March 2021 after having been established in 2019 to improve the working conditions of artisanal miners by managing and controlling production, purchasing, processing, and marketing of cobalt produced by artisanal methods. EGC entered into an offtake agreement with trading company Trafigura Group Pte. Ltd. (Singapore) in 2020, under which Trafigura would finance the creation of strictly controlled artisanal mining zones, the installation of ore-purchasing stations, and the costs related to transparent and traceable delivery of crude cobalt hydroxide to Trafigura. EGC was responsible for ensuring that the cobalt supplied under the agreement complied with Organisation for Economic Co-operation and Development due diligence guidance for responsible supply chains of minerals from conflict-affected and high-risk areas. In 2021, EGC was unable to begin purchasing cobalt from artisanal miners owing to a dispute with Huayou

subsidiary Congo Dongfang International Mining SARL over access to the Kasulo Mine in Lualaba Province, which EGC chose for its initial ore purchases (Trafigura Group Pte. Ltd., 2020; NS Energy, 2021; Reid, 2021).

Most of the ores and concentrates produced in Congo (Kinshasa) were processed domestically into crude cobalt hydroxide, an intermediate material that must be further refined. Some concentrates were exported and, in recent years, only small quantities were refined domestically into cobalt metal (table 8). Gécamines had been the sole producer of refined cobalt in the country since late 2015, when Kamoto Copper Company S.A. (KCC) (Glencore, 75%; Gécamines, 20%; and Simco Sarl, 5%) ceased production at its Luilu cobalt refinery. Since then, Gécamines ceased production of cobalt metal and produced cobalt hydroxide instead. In 2021, Hanrui Metal (Congo) Co. Ltd., a wholly owned subsidiary of Nanjing Hanrui Cobalt Co., Ltd. of China, decided to produce cobalt hydroxide instead of cobalt metal at its newly constructed copper refinery in Kolwezi, Lualaba Province, and converted the electrowinning production line from cobalt to copper. Hanrui Metal expected to begin production of cobalt hydroxide in mid-2022 (Katanga Mining Ltd., 2016, p. 1–2; Nanjing Hanrui Cobalt Co., Ltd., 2022, p. 15; Andries Gerbens, Director, Darton Commodities Ltd., written commun., June 7, 2023).

In 2021, three companies accounted for more than one-half of Congo (Kinshasa)'s estimated cobalt mine production. Glencore was the leading producer, followed by Eurasian Resources Group S.a.r.l. (ERG) of Luxemburg (40% of which was owned by the Government of Kazakhstan), and China Molybdenum Co., Ltd. (CMOC). In 2021, each of the companies significantly increased their cobalt production in Congo (Kinshasa) (China Molybdenum Co., Ltd., 2022, p. 17; Eurasian Resources Group S.a.r.l., 2022, p. 1; Glencore plc, 2022a, p. 243).

Glencore had majority ownership in two copper-cobalt mining and refining operations in Congo (Kinshasa)—KCC and Mutanda, both in Lualaba Province. In 2021, KCC produced crude cobalt hydroxide containing 23,800 t of cobalt, unchanged from production in 2020. During 2021, Glencore restarted production at the Mutanda operation and produced 3,900 t of cobalt in concentrate and hydroxide from stockpiled oxide ore. The operation had been on temporary care-and-maintenance status since late 2019 because of low cobalt prices and an oversupplied market (Glencore plc, 2022a, p. 63, 153, 243).

ERG had majority ownership in two copper-cobalt operations in Congo (Kinshasa)—Boss Mining SPRL, which remained on care-and-maintenance status in 2021, and Metalkol Roan Tailings Reclamation. ERG's Metalkol operation recovered copper and cobalt from historic tailings deposited in the Musonoi River Valley and at the Kingamyambo Tailings Dam in Haut Katanga Province. In 2021, Metalkol's production of salable crude cobalt hydroxide increased by 25% to 20,700 t of contained cobalt, making it the second-ranked producer after KCC (Eurasian Resources Group S.a.r.l., 2022, p. 1, 55, 68).

CMOC had majority ownership of Tenke Fungurume Mining S.A.R.L.'s copper-cobalt mining and refining operation in Lualaba Province. In 2021, Tenke Fungurume produced crude cobalt hydroxide containing 18,501 t of cobalt, 20% more than the 15,436 t produced in 2020, and ended the year with an inventory of 9,048 t of cobalt in hydroxide. During the year, CMOC made progress on projects to double cobalt production capacity at Tenke Fungurume. The company also began developing its Kisanfu project, which was a copper-cobalt mine and refinery approximately 33 kilometers southwest of Tenke Fungurume with planned capacity to produce 30,000 t/yr of cobalt in hydroxide during phase 1 (Daly, 2021a; China Molybdenum Co., Ltd., 2022, p. 18, 23, 34; Mining Technology, 2022).

Shalina Resource Ltd.'s (United Arab Emirates) subsidiary Chemaf S.A.R.L. produced crude cobalt hydroxide from concentrate produced at Chemaf's Etoile Mine near Lubumbashi and processed at an onsite refinery. The company's Usoke refinery remained under care-and-maintenance status following the cessation of an artisanal mining pilot project at Chemaf's Mutoshi Mine in 2020 (Thomson Reuters, 2020c; Cobalt Institute 2022, p. 26).

In 2021, Norin Mining Co, Ltd. (China) (formerly Wanbao Mining Co., Ltd.) and Groupe Managem (Morocco) began production at the Pumpi project in Katanga Province and by yearend produced 3,186 t of cobalt in crude cobalt hydroxide. The project was ramping up to a capacity of 5,000 t/yr of cobalt in hydroxide (Darton Commodities Ltd., 2022, p. 9; Groupe Managem 2022, p. 32, 116).

Cuba.—In 2021, Cuba ranked fifth in terms of global cobalt mine production. Moa Nickel S.A. (part of a 50–50 joint venture of Sherritt and General Nickel) mined nickel-cobalt laterites at its mining concessions in Holguin Province and produced intermediate nickel-cobalt sulfide (often called mixed sulfide precipitate or MSP), which was sent to the joint venture's Fort Saskatchewan refinery in Canada. The MSP contained 32,997 t of nickel and cobalt in 2021, 5% less than the 34,858 t produced in 2020. During the year, the Moa Joint Venture completed a feasibility study for a new slurry preparation plant to be completed in 2024. The plant was part of Sherritt's plan to expand nickel and cobalt production by 15% to 20% above the quantity produced in 2021 (table 7; Sherritt International Corp., 2022, p. 7–9, 16, 68).

The Government-owned Empresa Niquelífera Ernesto Che Guevara operation in Punta Gorda, Holguin Province, also mined and processed nickel-cobalt laterites. However, nickel and cobalt originating in Cuba could not be imported into the United States because of a United States embargo on imports from Cuba (U.S. Code, 2010; Darton Commodities Ltd., 2022, p. 11).

Finland.—Cobalt was recovered as a byproduct from two mining operations (one in central Finland and one in northern Finland) and a smelter in southern Finland, and was refined at plants in Harjvalta, Kokkola, and Sotkamo. Finland continued to be the second-ranked global producer of refined cobalt (table 8).

Boliden AB (Sweden) produced 592 t of cobalt in nickel concentrate from its open pit Kevitsa nickel-copper-PGM sulfide mine and beneficiation plant in Sodankyla, northern Finland, compared with 495 t in 2020. The company processed nickel concentrates from its Kevitsa operations and elsewhere at its Harjavalta smelter and sold the resulting nickel matte. In 2021, production at the smelter was negatively affected by the low sulfur content in the concentrate processed, extensive

maintenance, and a fire and slag explosion in the second half of the year (Boliden AB, 2022, p. 16–17, 24, 45, 119).

Terrafame Ltd. [majority owned by Finnish Minerals Group Ltd. (Government of Finland)] produced MSP at its polymetallic mining and bioheap-leaching operation in Sotkamo in central Finland. In 2021, the operation produced an estimated 580 t of cobalt in MSP based on reported nickel production, which was unchanged from that in 2020. By June, Terrafame had completed construction and started production at a new nickel-cobalt refinery adjacent to the mining and processing operation. The refinery was designed to convert MSP into nickel sulfate and cobalt sulfate for battery applications and had a full production capacity of 7,400 t/yr of cobalt sulfate containing an estimated 1,550 t/yr of cobalt (Terrafame Ltd., 2021, p. 3, 13–14, 23; 2022, p. 4).

PJSC MMC Norilsk Nickel (Nornickel) (Russia) owned and operated a nickel refinery at Harjavalta, where it produced two cobalt products—refined cobalt sulfate and an intermediate cobalt sulfate solution. The refinery processed nickel matte and converter matte from Kola MMC in Russia and feedstock and nickel salts from other companies (PJSC MMC Norilsk Nickel, 2022, p. 89).

Since 2019, ownership of the Kokkola cobalt business, known as Freeport Cobalt Oy, was split between Umicore, which had the cobalt refining and battery cathode precursor activities, and Koboltti Chemicals Holdings Ltd. (Bermuda) [owned by Freeport-McMoRan Inc. (United States), Lundin, and Gécamines], which owned the operations for producing cobalt chemicals, metal powders, and downstream catalysts, ceramics, and pigments. In September 2021, Jervois acquired Koboltti's shares in Freeport Cobalt and renamed it Jervois Finland. The acquisition included the manufacturing facility for downstream cobalt products; a capacity sharing agreement with Umicore for the Kokkola refinery, which allowed for Jervois to refine 6,250 t/yr of cobalt to supply its downstream production facility; and long-term feed supply contracts. The main feed for the refinery was crude cobalt hydroxide supplied under long-term agreements by CMOC's Tenke Fungurume and Glencore's Katanga and Mutanda operations in Congo (Kinshasa). The refinery also processed cobalt-bearing scrap from the battery, catalyst, and cemented carbide industries (Fastmarkets, 2019; Umicore N.V./S.A., 2019; Jervois Global Ltd., 2022, p. 18–19, 24).

Indonesia.—PT Vale Indonesia Tbk produced cobalt-bearing nickel matte from laterite ores at its integrated mining and smelting operation near Sorowako on Sulawesi Island. The matte was committed to Vale Canada Ltd. (80%) and Sumitomo Metal Mining Co., Ltd. (SMM) (Japan) (20%) under life-of-mine agreements. Most of the matte sold to Vale was sent to the company's nickel refinery in Matsusaka, Mie Prefecture, Japan (Vale S.A., 2022, p. 64, 67).

As part of the Indonesian Government's plan to process more nickel laterite ore domestically and to produce products for the battery industry, at least five high-pressure acid leaching (HPAL) plants were reportedly under construction in 2020, and two started production in 2021. The plants would process low-grade nickel, high-grade cobalt limonitic laterite ore to produce MHP and in some cases further refine the MHP to nickel sulfate and cobalt sulfate. PT Halmahera Persada Lygend operated the first Indonesian HPAL plant to reach production. The plant, located on Obi Island, North Maluku Province, had the capacity to produce 30,000 to 37,000 t/yr of MHP containing an estimated 4,400 t/yr of cobalt, the first batch of which was produced in May. Initial production from the plant would be delivered to China. In late December, PT Huayue Nickel Cobalt began production at its HPAL plant at Morowali, Central Sulawesi Province. The plant had the capacity to produce 6,000 t/yr of cobalt in MHP. Other HPAL plants under construction included PT Adhikara Cipta Mulia's plant at Konawe, Southeast Sulawesi Province; PT QMB New Energy Materials's plant at Morowali, Central Sulawesi Province; and PT Smelter Nikel Indonesia in Banten on the island of Java (CNBC Indonesia, 2020; Thomson Reuters, 2020b; Daly and others, 2021; Zhejiang Huayou Cobalt Co., Ltd., 2021a, b; PT Halmahera Persada Lygend, 2021).

Japan.—In 2021, Japan ranked fifth in terms of global production of refined cobalt. Cobalt was produced at two refineries operated by SMM. The Niihama nickel refinery in Ehime Prefecture produced cobalt metal, and the Harima refinery in Hyogo Prefecture produced cobalt chemical precursors for battery materials. Both refineries processed MSP produced at plants in the Philippines owned by SMM subsidiaries Coral Bay Nickel Corp. (Philippines) and Taganito HPAL Nickel Corp. (Philippines). The Niihama nickel refinery additionally processed nickel matte (containing cobalt) from PT Vale in Indonesia and additional cobalt-bearing nickel raw materials from elsewhere (Sumitomo Metal Mining Co., Ltd., 2022, p. 55, 57, 101).

Madagascar.—The Ambatovy joint venture [Sumitomo Corp. (Japan) and Korea Mine Rehabilitation and Mineral Resources Corp. (KOMIR) (formerly Korea Resources Corp.)] was Madagascar's sole nickel-cobalt mining, processing, and refining operation. Operations restarted in the quarter ending March 31, 2021, after being placed on care-and-maintenance status in late March 2020 in response to COVID-19 pandemic-related lockdown restrictions. In 2021, refined cobalt production, in the form of metal briquettes, more than doubled compared with that in 2020 (tables 7, 8; Ambatovy, 2022, p. 12–14, 20).

Mexico.—Minera y Metalúrgica del Boleo, S.A.P.I. de C.V. (MMB) [majority owned by KOMIR (Korea)] owned and operated the El Boleo project, which consisted of a copper-cobalt-zinc mine and refinery in Baja California Sur. In June, Mexico's Ministry of Environment and Natural Resources approved MMB's request from mid-2019 to extend the area available for mining, which would support 16 years of production at 800 t/yr of cobalt metal, 30,000 t/yr of copper, and 1,187 t/yr of zinc sulfate. The company stated the expansion was needed to continue operations at the mine, owing to depletion of ore reserves (Márquez and others, 2021; Peninsular Digital, 2021).

Morocco.—Compagnie de Tifnout Tighanimine (CTT) (a subsidiary of Groupe Managem) mined cobalt arsenide ores and produced crude cobalt hydroxide at Bou-Azzer. The hydroxide was refined to cobalt metal at CTT's Guemassa hydrometallurgical refinery north of Marrakech. In 2021, CTT produced 1,796 t of refined cobalt from mined and secondary (scrap) materials, a 26% decrease from the 2,416 t of refined cobalt produced in 2020. The production decrease was attributed

to elevated material costs and supply chain delays (Groupe Managem, 2022, p. 20, 38).

New Caledonia.—In 2021, estimated recoverable cobalt mine production was 50% less than that in 2020. In late March, Prony Resources New Caledonia, a consortium whose ownership included company management and employees, Grupo Acio Global (Spain), Société de Participation Minière du Sud Caledonien S.A.S., Trafigura, and local communities, acquired New Caledonia's sole cobalt producer, Vale Nouvelle-Calédonie S.A.S., from Vale. In April, Prony Resources restarted MHP production from its mining and HPAL processing plant at its Usine du Sud operation on the southern tip of New Caledonia's main island, which had been shut down since December 2020, following a protest at the site (table 7; Vale S.A., 2020; Prony Resources New Caledonia, 2021a, b).

Norway.—In 2021, Norway was the fourth-ranked global producer of refined cobalt. Glencore's production of cobalt metal at Nikkelverk, Norway's sole refinery, was 4,000 t, which was a 9% decrease from that in 2020. The company's Sudbury and Raglan operations in Canada supplied 28% of the cobalt refined at Nikkelverk; the remaining feed was a mix of intermediate products and secondary (scrap) materials sourced from other companies (table 8; Cobalt Institute, 2021, p. 17; Glencore plc, 2022a, p. 247).

Papua New Guinea.—In 2021, the Ramu nickel-cobalt joint venture between Metallurgical Corporation of China Ltd. (the majority owner and operator), Nickel 28 Capital Corp. (Canada), the Papua New Guinea Government, and landowners, produced the same amount of cobalt in MHP as it did in 2020. MHP produced at the joint venture's Basamuk HPAL processing plant from ore mined and beneficiated at the Kurumbukari nickel-cobalt laterite mine was exported to China to be refined (table 7; Darton Commodities Ltd., 2021, p. 12, 82; Nickel 28 Capital Corp., 2022, p. 4–5).

Philippines.—In 2021, the Philippines ranked sixth in global production of mined cobalt. Two companies, Coral Bay Nickel Corp. and Taganito HPAL Nickel Corp., operated HPAL processing plants that produced MSP from laterite ore mined in the Philippines. Coral Bay Nickel was a joint venture between SMM and Nickel Asia Corp., listed in order of share, with operations at the Rio Tuba Nickel Mine on Palawan Island. Taganito was a joint venture among SMM, Mitsui & Co., Ltd. (Japan), and Nickel Asia, listed in order of share, with operations at Nickel Asia's Taganito Mine in the northeastern region of Mindanao Island. During the year, production at Coral Bay Nickel was negatively affected by ongoing effects of the COVID-19 pandemic, and production at Taganito was negatively affected by equipment issues and inclement weather. The MSP from both operations was sent to SMM's Niihama and Harima refineries in Japan (table 7; Sumitomo Metal Mining Co., Ltd., 2022, p. 41, 57).

Russia.—In 2021, Russia ranked second in global cobalt mine production. The 18% decrease in estimated production of cobalt in concentrates compared with that in 2020 was attributed primarily to reduced ore production, owing in part to flooding of some subsurface mines on the Taymyr Peninsula, an emergency shutdown of the Nornickel beneficiation plant, and a decrease in cobalt recovery rate from nickel pyrrhotite concentrate (table 7; Ministry of Natural Resources and Environment of the Russian Federation, 2022, p. 222).

Russia ranked ninth in global production of refined cobalt. Nornickel was the main producer of mined cobalt in Russia and the sole producer of Russia's refined cobalt. The company recovered cobalt from copper-nickel sulfide ores mined and beneficiated at its Norilsk division on the Taymyr Peninsula and its Kola division on the Kola Peninsula. Concentrates from the Kola and Norilsk divisions were smelted at the Nadezhda Metallurgical Plant on the Taymyr Peninsula and sent for refining at the Kola MMC refinery. The Kola MMC refinery produced cobalt metal and a cobalt chemical intermediate that was sent to the Harjavalta Refinery in Finland for production of cobalt sulfate (table 8; PJSC MMC Norilsk Nickel, 2022, p. 78–79, 84–88).

South Africa.—The Nkomati nickel sulfide mine (a joint venture of African Rainbow Minerals Ltd. and Nornickel) ceased production in the quarter ending March 31 and was placed on care-and-maintenance status in preparation for closure. During calendar year 2021, the mine produced 105 t of cobalt in nickel concentrate compared with 708 t in 2020. Concentrate from Nkomati was sold to Metal Trade Overseas AG (African Rainbow Minerals Ltd., 2021a, p. 66, 72; 2021b, p. 14).

Cobalt also was produced as a byproduct from some of South Africa's PGM operations. Two companies produced refined cobalt. Rustenburg Base Metals Refiners (Proprietary) Ltd. (a subsidiary of Anglo American plc of the United Kingdom) produced cobalt sulfate at its base-metals refinery near Rustenburg, North West Province. Impala Platinum Holdings Ltd. (Implats) produced cobalt metal powder at its base-metals refinery near Springs, Gauteng Province. In addition to refining concentrates from PGM ore mined in South Africa, some of the cobalt produced by Implats was recovered from concentrates produced at the Mimosa platinum mine in Zimbabwe (Impala Platinum Holdings Ltd., 2020; Anglo American Platinum Ltd., 2022, p. 127; Sibanye Stillwater Ltd., 2022, p. 91).

Two other platinum producers, Northam Platinum Holdings Ltd. and Sibanye Stillwater, had base-metals refineries that processed materials containing nickel and cobalt. In 2021, Thakadu Battery Materials Pty. Ltd. began production at its plant at Sibanye Stillwater's Marikana base-metals refinery to refine the operation's crude nickel sulfate to battery-grade nickel sulfate and crude cobalt hydroxide (Cape Business News, 2021; Northam Platinum Holdings Ltd., 2022, p. 37, 45; Thakadu Group, 2021a, b).

Turkey.—Two companies recovered cobalt from ores mined in Turkey. Meta Nikel Kobalt Madencilik Sanayi ve Ticaret A.Ş. (jointly owned by Vestel Elektronik Sanayi ve Ticaret A.Ş. and Zorlu Holding A.Ş.) mined and processed laterite ore in Gordes, Manisa Province. In 2021, Meta Nikel produced MHP containing 323 t of cobalt, a 27% increase from the 254 t produced in 2020. The company planned to invest in a 50% increase in production capacity at the HPAL plant and to research the production of value-added nickel and cobalt products, including cobalt carbonate, sulfate, and metal (Vestel Elektronik Sanayi ve Ticaret A.Ş., 2022, p. 106–107, 224; Zorlu Group, 2023, p. 9, 12–13).

Eti Bakir A.Ş. (Cengiz Holding A.Ş.) produced copper concentrate and cobalt-bearing pyrite concentrate from its Küre mining operation in Kastamonu Province. The company roasted the pyrite concentrate to produce sulfuric acid for its Mazidağı phosphate plant in Mardin Province. The calcine generated by roasting the pyrite was then treated at the Mazidağı plant using a hydrometallurgical process to recover cobalt as crude cobalt carbonate. In 2021, Eti Bakir produced an estimated 2,100 t of cobalt in carbonate, a 9% decrease from the 2,300 t estimated production in 2020 (Metso Outotec Corp., 2019; Darton Commodities Ltd., 2022, p. 11; Eti Bakir A.Ş., undated).

Zambia.—According to the Zambian Ministry of Finance and National Planning, in 2021, production of mined cobalt was 247 t, a decrease of 22% from that in 2020. Chambishi Metals [owned by ERG and Government-owned ZCCM Investments Holdings Plc (ZCCM–IH)] was Zambia's sole producer of refined cobalt. The refinery remained on care-and-maintenance status through 2021, owing to a shortage of concentrate feed (table 7; Darton Commodities Ltd., 2021, p. 76; Ministry of Finance and National Planning, 2022, p. 14, 68).

Konkola Copper Mines Plc (KCM) [owned by Vedanta Resources Ltd. (United Kingdom) and ZCCM–IH] processed concentrates from its Zambian copper mining operations and from other sources at its Nchanga copper smelter. The smelter had the capability to recover cobalt as an intermediate copper-iron-cobalt alloy. A dispute between Vedanta and ZCCM–IH over the appointment of a provisional liquidator to continue the business of KCM and take possession and dispose of its assets, which began in 2019, had not been resolved by yearend 2021, although KCM remained operational (Darton Commodities Ltd., 2022, p. 10; Vedanta Resources Ltd., undated; ZCCM Investments Holdings Plc, 2022, undated).

Mabiza Resources Ltd., a subsidiary of Consolidated Nickel Mines Ltd. (CNM) (United Kingdom), produced nickel concentrate at the Munali nickel sulfide mine in southern Zambia. The concentrate contained 3,672 t of nickel and an estimated 210 t of cobalt, based on average concentrate grades of 12.3% nickel and 0.7% cobalt (Consolidated Nickel Mines Ltd., 2022, p. 12; undated).

In 2021, Jubilee Metals Group Plc (United Kingdom) continued progress on multiple aspects of its plan to produce refined copper and cobalt from tailings generated during previous mining operations and run-of-mine concentrates. Jubilee had joint-venture agreements to secure rights to multiple tailings deposits and continued with evaluation of those deposits in 2021. The company's strategy was to have two operation centers, each with tailings deposits, beneficiation plants, and a refinery. The southern center would incorporate Jubilee's multi-metal Sable refinery near Kabwe and also process run-of-mine concentrates. In 2021, Jubilee signed a memorandum of understanding with Mopani Copper Mines Plc, a subsidiary of ZCCM–IH, for access to copper and cobalt refining capacity at Mopani's refinery in Kitwe, which it renamed Leopard. The Leopard refinery was to be part of Jubilee's northern operation center. During the year, Jubilee continued construction on the first of three planned beneficiation plants (Jubilee Metals Group Plc, 2021, p. 17–19, 123–124).

Zimbabwe.—Bindura Nickel Corp. Ltd., Mimosa Mining Co. (jointly owned by Implats and Sibanye Stillwater), and Zimplats Holdings Ltd. generated small quantities of byproduct cobalt from their nickel and platinum mining operations (Bindura Nickel Corp. Ltd., 2022, p. 8; Zimplats Holdings Ltd., 2022, p. 171).

Outlook

Historically, trends in refined cobalt consumption generally followed those of global industrial production. Increases in cobalt consumption by the rechargeable battery industry, initially for personal electronics and increasingly for electric vehicles and energy storage systems, have resulted in annual growth rates for global cobalt consumption exceeding growth rates for the global gross domestic product (Taarland, 2009, p. 7; Darton Commodities Ltd., 2021, p. 37–39; Cobalt Institute, 2022, p. 40).

Several industry analysts forecast that global cobalt mine and intermediate production will increase significantly in the near to medium term, particularly from mines and processing plants in Congo (Kinshasa) and Indonesia. Supply of refined cobalt is expected to keep pace with the availability of mined and intermediate feed supplies. Cobalt from recycling end-of-life lithium-ion batteries is expected to increase over time. Most analysts forecast that increased supply will bring the cobalt market into or near to balance through 2023, but that without investment in additional mine projects, increasing demand from the electric vehicle industry will result in a deficit between cobalt supply and consumption in 2024 or 2025 if cobalt-bearing batteries remain prevalent (Argus Metals International, 2022, p. 55; Cobalt Institute, 2022, p. 40–42; Darton Commodities Ltd., 2022, p. 53–54, 57; Yu, 2022, p. 16).

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TABLE 1
SALIENT COBALT STATISTICS[1]

(Metric tons, cobalt content, unless otherwise specified)

		2017	2018	2019	2020	2021
United States:						
Mine production[e]		640	480	500	600	650
Consumption:[2]						
Estimated		9,240	9,290	9,050	7,260	7,270
Apparent[3]		8,950	7,680	12,500	8,480 [r]	6,650
Imports for consumption		11,900	11,900	13,900	9,740	9,800
Exports		5,690	6,980	4,080	3,430 [r]	4,930
Stocks, December 31:						
Industry[e, 2, 4]		1,020	1,060	1,090	952	1,010
London Metal Exchange Ltd. (LME), U.S. warehouses		160	130	102	82	50
U.S. Government:[5]						
Metal		302	302	302	302	302
Lithium-cobalt oxide	gross weight	1	1	1	1	1
Lithium-nickel-cobalt-aluminum oxide	do.	2	2	2	3	3
Cobalt alloys	do.	(6)	3	3	11	14
Price, metal:						
U.S. spot[7]	dollars per pound	26.97	37.43	16.95	15.70	24.21
LME, cash[8]	do.	25.28	32.94	14.88	14.21	23.17
World:						
Production:[9]						
Mine		128,000	149,000	155,000 [r]	147,000 [r]	164,000
Refinery		119,000	126,000	139,000 [r]	147,000 [r]	148,000
Stocks, December 31, LME[10]		580	863	685	451	256

[e]Estimated. [r]Revised. do. Ditto.
[1]Table includes data available through September 12, 2022. Data are rounded to no more than three significant digits, except prices.
[2]Includes reported data and U.S. Geological Survey estimates.
[3]Defined as imports minus exports plus adjustments for Government and industry stock changes plus secondary production, as estimated from consumption of purchased scrap.
[4]Stocks held by cobalt processors and consumers.
[5]Source: Defense Logistics Agency Strategic Materials.
[6]Less than ½ unit.
[7]Annual average U.S. spot price for minimum 99.8% cobalt cathode reported by S&P Global Platts Metals Week.
[8]Annual average mean of the cash buyer price and cash seller price, cobalt briquettes, cathode, ingot, coarse powder, or rounds, converted from dollars per metric ton. Effective January 19, 2018, LME ceased trading cobalt ingot and increased the minimum grade of cobalt metal to be delivered under the cobalt contract from 99.3% cobalt to 99.8% cobalt.
[9]May include estimated data.
[10]Stocks held in Asia, Europe, and the United States.

TABLE 2
U.S. ESTIMATED CONSUMPTION AND STOCKS OF COBALT[1, 2]

(Metric tons, cobalt content)

	2020	2021
Consumption by end use:		
Steels and other alloys, excludes superalloys[3]	1,180	1,180
Superalloys	3,020	3,220
Cemented carbides[4]	629	708
Chemical and ceramic uses	2,420	2,170
Total	7,260	7,270
Consumption by form:		
Chemical compounds, organic and inorganic[5]	2,140	2,150
Metal	3,100	3,320
Purchased scrap	2,010	1,800
Total	7,260	7,270
Stocks, December 31:[6]		
Chemical compounds, organic and inorganic[5]	387	388
Metal	W	W
Purchased scrap	W	W
Total	952	1,010

W Withheld to avoid disclosing company proprietary data; included in "Stocks, December 31: Total."

[1]Table includes data available through September 12, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes reported data and U.S. Geological Survey estimates.
[3]Includes magnetic alloys, nonferrous alloys, wear- and corrosion-resistant alloys, welding materials, and other metallic uses not listed.
[4]Includes cast carbide dies or parts, cemented and sintered carbides, and diamond tool matrices.
[5]Includes oxides.
[6]Stocks held by cobalt processors and consumers.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM[1]

		2020			2021		
Form	HTS[2] codes	Gross weight (metric tons)	Cobalt content[3] (metric tons)	Value[4] (thousands)	Gross weight (metric tons)	Cobalt content[3] (metric tons)	Value[4] (thousands)
Metal[5]	8105.20.6000 and 8105.20.9000	8,140	8,140	$282,000	7,210	7,210	$323,000
Oxides and hydroxides	2822.00.0000	1,260	910	30,600	2,220	1,600	74,700
Other:							
Acetates	2915.29.3000	171	41	1,550	769	185	10,700
Carbonates	2836.99.1000	702	323	12,600	584	269	13,500
Chlorides	2827.39.6000	81	20	795	115	29	1,230
Sulfates	2833.29.1000	1,130 r	305 r	8,660 r	1,850	500	15,000
Total		11,500	9,740	336,000	12,800	9,800	439,000

rRevised.
[1]Table includes data available through September 12, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States.
[3]Estimated from gross weight using the following percentages: metal, 100%; oxides and hydroxides, 72%; acetates, 24%; carbonates, 46%; chlorides, 25%; and sulfates, 27%.
[4]Customs value.
[5]Unwrought cobalt, excluding alloys and waste and scrap.

Source: U.S. Census Bureau.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY OR LOCALITY[1]

	Metal[2]			Oxides and hydroxides[3]			Other forms[4]			Total		
	Quantity (metric tons)			Quantity (metric tons)			Quantity (metric tons)			Quantity (metric tons)		
Country or locality	Gross weight	Cobalt content[6]	Value[5] (thousands)	Gross weight	Cobalt content[6]	Value[5] (thousands)	Gross weight	Cobalt content[6]	Value[5] (thousands)	Gross weight	Cobalt content[6]	Value[5] (thousands)
2020:												
Australia	722	722	$23,900	20	15	$351	--	--	--	742	737	$24,200
Belgium	6	6	217	275	198	7,560	16	7	$285	296	210	8,060
Brazil	--	--	--	--	--	--	211	70	2,410	211	70	2,410
Canada	1,950	1,950	61,100	(7)	(7)	4	1	(7)	12	1,950	1,950	61,100
China	33	33	862	48	34	949	131	39	1,310	212	107	3,120
Finland	325	325	11,600	388	280	9,420	1,500	511	17,400	2,210	1,120	38,400
Germany	56	56	3,000	2	1	51	11 r	3 r	82 r	69 r	60 r	3,130 r
Japan	1,340	1,340	47,000	--	--	--	10	2	56	1,350	1,350	47,000
Korea, Republic of	(7)	(7)	5	41	29	918	--	--	--	41	29	923
Madagascar	397	397	14,000	--	--	--	--	--	--	397	397	14,000
Mexico	61	61	1,940	1	1	20	1	(7)	12	63	62	1,970
Morocco	356	356	11,000	--	--	--	--	--	--	356	356	11,000
Norway	1,910	1,910	79,300	--	--	--	--	--	--	1,910	1,910	79,300
Russia	713	713	23,600	--	--	--	--	--	--	713	713	23,600
South Africa	205	205	1,620	--	--	--	--	--	--	205	205	1,620
Taiwan	--	--	--	58	42	1,080	72	19	615	129	61	1,700
United Kingdom	52	52	2,550	406	292	9,650	131	35	1,370	589	380	13,600
Other	9	9	579	26	19	569	3	1	73	38	29	1,220
Total	8,140	8,140	282,000	1,260	910	30,600	2,080 r	689 r	23,600 r	11,500	9,740	336,000
2021:												
Australia	191	191	9,770	17	12	446	--	--	--	208	203	10,200
Belgium	25	25	1,410	508	366	18,300	144	41	1,770	677	431	21,500
Brazil	--	--	--	42	30	1,340	528	158	4,030	571	188	5,370
Canada	904	904	38,200	--	--	--	3	1	61	907	905	38,300
China	29	29	771	65	47	1,560	102	28	916	196	104	3,250
Finland	510	510	24,900	774	557	25,100	1,460	471	20,300	2,740	1,540	70,300
Germany	103	103	6,190	1	1	43	31	9	376	135	113	6,610
Japan	1,120	1,120	44,400	--	--	--	22	5	114	1,140	1,120	44,500
Korea, Republic of	(7)	(7)	30	42	30	1,270	--	--	--	43	31	1,300
Madagascar	120	120	6,110	--	--	--	--	--	--	120	120	6,110
Mexico	60	60	2,120	4	3	82	19	5	280	83	68	2,480
Morocco	142	142	5,320	--	--	--	--	--	--	142	142	5,320
Norway	3,150	3,150	147,000	--	--	--	--	--	--	3,150	3,150	147,000
Russia	748	748	31,600	--	--	--	(7)	(7)	4	748	748	31,600
South Africa	47	47	1,620	--	--	--	--	--	--	47	47	1,620
Taiwan	--	--	--	153	110	5,740	620	157	6,410	774	267	12,200
United Kingdom	52	52	3,380	608	438	20,500	380	104	5,950	1,040	595	29,900
Other	12	12	518	9	7	293	10	3	183	32	22	994
Total	7,210	7,210	323,000	2,220	1,600	74,700	3,320	982	40,400	12,800	9,800	439,000

r Revised. -- Zero.

[1] Table includes data available through September 12, 2022. 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; includes cobalt cathode and cobalt metal powder; may include intermediate products of cobalt metallurgy. Harmonized Tariff Schedule of the United States (HTS) codes 8105.20.6000 and 8105.20.9000.

[3] HTS code 2822.00.0000.

[4] Cobalt acetates, cobalt carbonates, cobalt chlorides, and cobalt sulfates under HTS codes 2827.39.6000, 2833.29.1000, 2836.99.1000, and 2915.29.3000.

[5] Customs value.

[6] Estimated from gross weight using the following cobalt content percentages: metal, 100%; oxides and hydroxides, 72%; acetates, 24%; carbonates, 46%; chlorides, 25%; and sulfates, 27%.

[7] Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 5

U.S. EXPORTS OF COBALT, BY COUNTRY OR LOCALITY[1, 2]

	Metal[3]		Oxides and hydroxides[4]		Acetates[5]		Chlorides[6]		Total	
Country or locality	Gross weight (metric tons)	Value[7] (thousands)	Gross weight (metric tons)	Value[7] (thousands)	Gross weight (metric tons)	Value[7] (thousands)	Gross weight (metric tons)	Value[7] (thousands)	Cobalt content[8] (metric tons)	Value[7] (thousands)
2020:	3,290 r	$97,600 r	74	$2,630	372	$3,780	3	$52	3,430 r	$104,000
2021:										
Argentina	4	252	--	--	--	--	--	--	4	252
Belgium	47	2,250	19	135	--	--	--	--	61	2,380
Brazil	113	6,550	(9)	19	--	--	--	--	114	6,570
Canada	1,470	13,300	8	316	--	--	--	--	1,470	13,600
China	117	5,210	4	161	--	--	--	--	120	5,370
France	360	8,700	--	--	--	--	--	--	360	8,700
Germany	345	17,500	1	27	--	--	--	--	346	17,600
India	126	3,430	(9)	5	--	--	--	--	126	3,430
Indonesia	4	199	--	--	--	--	--	--	4	199
Ireland	919	28,800	--	--	--	--	--	--	919	28,800
Italy	7	935	--	--	--	--	--	--	7	935
Japan	145	10,200	(9)	3	--	--	--	--	145	10,200
Korea, Republic of	88	4,910	--	--	1	29	--	--	88	4,930
Luxembourg	131	5,220	--	--	--	--	--	--	131	5,220
Malaysia	12	713	--	--	--	--	--	--	12	713
Mexico	20	2,320	4	114	1	18	1	15	24	2,460
Netherlands	45	1,170	--	--	--	--	--	--	45	1,170
Poland	41	42	--	--	--	--	--	--	41	42
Saudi Arabia	9	988	--	--	--	--	--	--	9	988
Singapore	40	3,560	--	--	--	--	--	--	40	3,560
Slovakia	6	94	--	--	--	--	--	--	6	94
Switzerland	25	720	--	--	--	--	--	--	25	720
Taiwan	50	1,450	1	9	6	58	(9)	13	52	1,530
Tunisia	124	2,890	--	--	--	--	--	--	124	2,890
Turkey	24	1,050	--	--	--	--	--	--	24	1,050
United Arab Emirates	6	402	--	--	--	--	--	--	6	402
United Kingdom	613	14,900	(9)	7	--	--	--	--	613	14,900
Other	14	1,090	6	269	--	--	--	--	18	1,360
Total	4,900	139,000	43	1,060	8	105	1	28	4,930	140,000

rRevised. -- Zero.

[1]Table includes data available through September 12, 2022. 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 exported 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 exported under Schedule B of the United States codes 8105.20.0000 and 8105.30.0000.

[4]Schedule B code 2822.00.0000.

[5]Schedule B code 2915.29.3000.

[6]Schedule B code 2827.39.6000.

[7]Free alongside ship value.

[8]Estimated from gross weight using the following cobalt content percentages: metal, 100%; oxides and hydroxides, 72%; acetates, 24%; and chlorides, 25%.

[9]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 6
WORLD ANNUAL COBALT REFINERY
CAPACITY, DECEMBER 31, 2021[1, 2]

(Metric tons, cobalt content)

Country or locality	Capacity
Australia	6,900 e
Belgium	3,000 e
Brazil	2,000
Canada	8,120
China	166,000
Congo (Kinshasa)	6,050 e
Finland[3]	18,000 e
France	600
India	1,000 e
Japan	5,500 e
Korea, Republic of	1,200
Madagascar	5,600
Mexico	1,700
Morocco	2,800
Norway	5,200
Russia	3,000
South Africa	3,000 e
Uganda	720
Zambia	9,600
Total	250,000

eEstimated.
[1]Table includes data available through September 30, 2022.
[2]Includes standby capacity. Refinery products include cobalt metal, metal powders, oxides, and (or) salts.
[3]Increased to include capacity for Terrafame Ltd.'s refinery, which began production in 2021.

TABLE 7
COBALT: WORLD MINE PRODUCTION, BY COUNTRY OR LOCALITY[1, 2]

(Metric tons, cobalt content)

Country or locality[3]	2017	2018	2019	2020	2021
Australia[4]	5,034	4,878	5,741 r	5,626 r	5,295
Brazil	185	-- e	30 e	160 e	266
Canada[5]	3,704	3,279	4,365 r	4,775 r	4,361
China	2,500 e	2,000 e	2,241	2,200 e	2,200 e
Congo (Kinshasa)[e, 6]	80,000	104,000	107,000	98,000	119,000
Cuba[e, 7]	3,900	3,600 r	3,800	3,700 r	4,000
Finland[8]	1,000 e	1,377	1,454	1,559	1,084
Indonesia[e, 9]	1,200	1,200	1,100	1,100	1,600
Madagascar[e, 10]	3,600	3,300	3,400	970 r	2,800
Mexico[e]	1,000	1,400	1,100	1,000	1,100
Morocco[e, 11]	2,300	2,300	2,300	2,300	2,300
New Caledonia[e, 12]	2,780	2,100	1,700	2,200	1,100
Papua New Guinea[13]	3,308	3,275	2,911	2,941	2,953
Philippines[e, 14]	3,800	3,600	4,300 r	4,100 r	3,600
Russia[15]	8,900	8,700	9,400 r	9,700 r	8,000 e
South Africa[e]	2,300	2,100 r	2,100	1,900 r	540
Turkey[16]	220	259	620 r, e	2,600 r, e	2,400 e
United States[e, 15]	640	480	500	600	650
Zambia	990	835	379	316	247
Zimbabwe	445	402 r	402 r	956 r	230
Total	128,000	149,000	155,000 r	147,000 r	164,000

[e]Estimated. [r]Revised. -- Zero.

[1]Table includes data available through August 16, 2022. All data are reported unless otherwise noted; totals may include estimated data. Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Figures represent recoverable cobalt content from ore, concentrate, or intermediate products from cobalt, copper, nickel, platinum, or zinc operations.

[3]Other copper-, iron (pyrite)-, nickel-, platinum-, or zinc-producing countries and (or) localities also may have produced ore containing cobalt as a byproduct component, but recovery was small or zero.

[4]Cobalt content of lateritic nickel ore and nickel concentrate reported by the government of Western Australia.

[5]Data for 2017–18 are mineral production reported by Natural Resources Canada. Data for 2019–21 are recoverable cobalt in concentrate shipped reported by Statistics Canada.

[6]Determined from reported or estimated cobalt content of materials originating from mining and processing operations in Congo (Kinshasa) such as ore, concentrate, refined cobalt metal, and intermediate products including crude cobalt alloys, crude cobalt hydroxide, and crude cobalt carbonate produced from cobalt ore and concentrate, tailings, or slag.

[7]Determined from estimated cobalt content of nickel-cobalt sulfide production and estimated cobalt content of ammoniacal liquor production.

[8]Data prior to 2018 exclude cobalt in low-grade cobalt-nickel concentrate that was stockpiled while a marketable product was being developed.

[9]Determined from estimated cobalt content of nickel matte plus estimated cobalt content of nickel-cobalt hydroxide.

[10]Estimated cobalt content of ore production based on reported cobalt metal powder production and nickel recovery rates.

[11]Cobalt content of concentrate estimated from reported or estimated gross weight.

[12]Cobalt content of cobalt carbonate and nickel hydroxide.

[13]Cobalt content of nickel-cobalt hydroxide.

[14]Cobalt content of nickel-cobalt sulfide.

[15]Cobalt content of concentrates.

[16]Cobalt content of cobalt carbonate and nickel-cobalt hydroxide.

TABLE 8
COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY OR LOCALITY[1, 2]

(Metric tons, cobalt content)

Country or locality and form	2017	2018	2019	2020	2021
Australia, metal powder	3,000	3,200	3,700	3,300	2,800
Belgium, metal powder, oxide, hydroxide[e, 3]	1,590 [r]	1,650	1,500	1,300	1,000
Brazil, metal	46 [4]	8 [4]	-- [5]	-- [5]	--
Canada, metal, metal powder, oxide	6,355 [6]	6,349	6,075	5,965	6,045
China, metal, metal powder, oxide, salts[e]	75,000	83,100	95,000 [r]	106,000 [r]	110,000
Congo (Kinshasa), metal[7]	120	60	-- [e]	-- [e]	-- [e]
Finland, metal powder and salts[8]	13,585	14,295	14,283	15,148	14,400 [e, 9]
France, chloride	277 [4]	48 [4]	90 [e]	90 [e]	110 [e]
India, metal and salts	100 [4]	100 [4]	NA [10]	NA [10]	NA [10]
Japan, metal	4,159 [4]	3,669 [4]	4,000 [r, e]	4,200 [r, e]	3,500 [3]
Madagascar, metal powder	3,053	2,852	2,897 [r]	833 [r]	2,100 [e]
Mexico, metal	420 [e]	226	215	190 [e]	220 [e]
Morocco, metal	1,924	1,806	2,397	2,416	1,796
Norway, metal	3,473	4,166	4,354	4,384 [r]	4,000
Russia, metal	2,077 [4]	1,800 [4]	2,000 [e]	1,800 [3]	1,500 [3]
South Africa, metal powder and sulfate	1,065 [r]	1,007 [r]	1,027 [r]	897 [r]	355
Zambia, metal	2,520 [4]	1,613 [4]	1,500 [11]	100 [r, 11]	--
Total	119,000	126,000	139,000 [r]	147,000 [r]	148,000

[e]Estimated. [r]Revised. NA Not available. -- Zero.

[1]Table includes data available through August 16, 2022. All data are reported unless otherwise noted; totals may include estimated data. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

[3]Source: Darton Commodities Ltd.

[4]Source: Cobalt Institute (formerly Cobalt Development Institute).

[5]Source: Companhia Brasileira de Alumínio.

[6]Includes cobalt oxide.

[7]Does not include production of cobalt in alloys, carbonate, hydroxide, and other materials that would require further refining.

[8]Source: Geological Survey of Finland.

[9]Includes estimated production at Terrafame Ltd.'s nickel-cobalt refinery, which began production in June 2021.

[10]Refined cobalt may be produced from imported materials, but available information was inadequate to make reliable estimates of output.

[11]Source: Eurasian Resources Group.