NICKEL

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Stainless steel accounted for more than 60% of primary nickel consumption in the world (Falconbridge Limited, 2005a, p. 11). However, in the United States, this percentage was only 44% because of the relatively large number of specialty metal industries and readily available stocks of scrap. Cupronickel alloys, electroless plating, electrolytic plating, high-temperature nickel-chromium alloys, naval brasses, and superalloys and related aerospace alloys are some of the specialty uses. Increasing amounts of nickel metal foam are being used in the manufacture of rechargeable batteries.

Nickel in excess of 8% is needed to produce the austenitic microstructure in 300-series nonmagnetic stainless steels. The nickel content of some austenitic grades can be as high as 22%. All stainless steels contain a minimum of 10.5% chromium, which forms a thin protective film of chromium oxide on the surface of the steel, minimizing corrosion. If nickel is not added to the melt, the stainless steel forms a ferritic microstructure and is magnetic. Duplex stainless steels (alloys with a balanced ferrite-austenite microstructure) generally contain only 2.5% to 8.0% nickel. Sometimes, smaller quantities of nickel (0.2% to 3.8%) are incorporated into low alloy steels to improve their resistance to corrosion. Increasing nickel prices since 2001 have encouraged substitution of duplex, ferritic, or martensitic stainless for austenitic in some applications.

Largely fueled by increased use of stainless steel worldwide and strong economic growth in China, global nickel demand has been growing 2% to 8% per year since 2001 (Inco Limited, 2005, p. 22-27). Demand for nickel in batteries has grown dramatically since 1995, but still accounts for less than 5% of world nickel demand. The world nickel industry was operating close to capacity in 2004.

Legislation and Government Programs

Decontamination of Radioactive Nickel Metal.—The U.S. Department of Energy (DOE) had been recovering nickel scrap contaminated by low-level radioactivity as part of its decommissioning activities at former nuclear defense sites. DOE had about 9,400 metric tons (t) of volumetrically contaminated ingots of nickel metal stored at its uranium enrichment facility in Paducah, KY. The principal contaminants were technetium-99 and uranium-235. Past decommissioning activities at Oak Ridge, TN, also have generated 6,000 t of contaminated shredded nickel scrap. Planned decommissioning activities at Oak Ridge, Paducah, and Portsmouth, OH, were expected to generate an additional 20,000 t of shredded scrap (Sheely, 2005).

New U.S. Coinage.—As part of the 50 State Quarters™ Program, the U.S. Mint produced 2.40 billion commemorative quarters (25-cent coins) in 2004, up from 2.28 billion in 2003. A total of 23.70 billion of the cupronickel clad coins was minted between December 1998 and December 2004. Between 30 billion and 50 billion quarters will have been minted when the program ends in December 2008, down somewhat from previous forecasts. Since each coin weighs 5.67 grams (g) and contains 8.33% nickel, 1,134 t of nickel ended up in the five commemoratives released in 2004.

The U.S. Mint began releasing the new golden-colored dollar coin in January 2000. Between January 2000 and December 2003, 1.44 billion dollar coins were minted. An additional 5.3 million were made in 2004. The dollar coin contains 2.0% nickel. The coin, which weighs 8.1 g, is clad with pure copper metallurgically bonded to outer layers of manganese brass containing 4% nickel (U.S. Mint, 2003§[1]). The U.S. Mint began modifying the Jefferson nickel (5-cent coin) in late 2003 to commemorate the bicentennials of the Louisiana Purchase and the expedition of Lewis and Clark (Public Law 108-15). Two new designs were released in 2004 as part of the Westward Journey series. Each coin weighs 5.0 g and comprises solid cupronickel with a nickel content of 25%. The U.S. Mint produced 1.45 billion of the new Jefferson nickels in 2004. Two additional designs were scheduled for release in 2005 (U.S. Mint, 2004§, 2005§).

New Michigan Mining Law.—On December 27, the State of Michigan enacted a law regulating the underground mining of sulfide ores for nonferrous metals. The new law (Public Act No. 449 of 2004) was designed to protect the environment, while ensuring that mining companies could develop economically promising copper-nickel sulfide deposits in Michigan (Eggert, 2004§).

Exploration and Development

Michigan Exploration Project.—At the present time, there are no active underground metal mines operating in Michigan. However, Kennecott (a subsidiary of London, United Kingdom-based Rio Tinto Plc) headquartered in Salt Lake City, UT, is considering developing an underground nickel-copper mine in the Yellow Dog Plains area of Marquette County (Jackman, 2005). In October 2003, Kennecott formally announced the startup of its evaluation program, now called the Eagle Project (Federal Reserve Bank of Minneapolis, 2004§; Rebers, 2003§). On April 1, 2004, the Eagle Project was advanced from an exploration project to a potential development project. The proposed mine site is about 40 kilometers (km) (25 miles) northwest of the city of Marquette. Kennecott geologists estimated that the deposit contained 5 million metric tons (Mt) of sulfide ore grading 3.5% nickel and 3.0% copper. Kennecott was conducting environmental, economic, and engineering

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

studies to determine the feasibility of the project. The proposed mine would be the only primary-nickel mine in the United States (Kennecott Minerals Company, 2004).

Alaskan Exploration Projects.—Several companies were actively exploring for copper, nickel, and platinum-group elements (PGEs) in the Alexander Platinum Belt of southeastern Alaska. Freegold Ventures Ltd., Lonmin Plc, and Pacific Northwest Capital Corp. teamed up to evaluate ultramafic targets in the Union Bay area near Ketchikan. The exploration was concentrated on a 12-by-7- km zoned Ural-type complex with a dunite core ringed by pyroxenites (Szumigala and Hughes, 2005, p. 11). Freegold acquired the property in 2000 after reviewing the PGE potential of the Alexander Belt.

Quaterra Resources Inc. was exploring for copper, nickel, and PGEs on Duke Island, off the southwestern corner of Misty Fjords National Monument, 48 km southeast of Ketchikan. The Duke Island complex consists of two separate, zoned ultramafic bodies—Judd Harbour and Hall Cove—which are thought to join at depth. Each complex has a dunite-peridotite core (Quaterra Resources Inc., 2005).

Minnesota Development Projects.—PolyMet Mining Corp. of Vancouver, British Columbia, Canada, was in the early stages of developing a copper-nickel-PGE deposit in northeastern Minnesota. The 250-Mt sheet-like deposit of disseminated chalcopyrite, pentlandite, and other sulfides lies on the western edge of the Duluth Complex, near the Iron Range towns of Babbitt and Hoyt Lakes. An additional 1.2 billion to 1.6 billion metric tons (Gt) of similar sulfide resources has been identified in the Babbitt-Hoyt Lakes region. The Duluth Complex is composed largely of gabbroic rocks and covers 5,000 square kilometers (km^2) in St. Louis, Lake, and Carlton Counties.

The strip mine proposed by PolyMet would initially produce 25,000 metric tons per day (t/d) of ore and have a design capacity of 32,000 t/d. Mining would be similar to that on the Iron Range. The ore would be shipped to the neighboring Cliffs Erie taconite mill near Hoyt Lakes for crushing, grinding, and subsequent flotation. Polymet optioned a large part of the mothballed taconite plant from Cleveland-Cliffs Inc on February 16 and was planning to construct a state-of-the-art autoclave near the existing concentrator. Downstream hydrometallurgical processing would be performed in an adjoining renovated building. The hydrometallurgical facility would employ the PLATSOL™ Process developed by SGS Lakefield Research Limited. The sulfide ore was expected to average 0.43% copper, 0.12% nickel, and 0.009% cobalt. Flotation of the ore was expected to produce a bulk concentrate, averaging 15.5% copper, 3.59% nickel, and 0.15% cobalt, with significant precious metals. The proposed facility would produce 33,000 metric tons per year (t/yr) of copper cathode, 7,800 t/yr of nickel plus cobalt in a mixed hydroxide precipitate, and 3.73 t/yr (120,000 troy ounces per year) of contained gold and PGE in a precious metals precipitate. Bateman Engineering Pty. Ltd. of Brisbane, Australia, was scheduled to complete the final feasibility document in early 2006. If approved, construction could begin at the end of 2006 and be completed by the beginning of 2008. Purchase of the Cliffs Erie facility would save nearly $200 million in capital development costs. Capital costs for the startup phase of the project are expected to be about $235 million (Murray, 2005; PolyMet Mining Corp., 2005§).

Production

Primary Production.—The United States did not have any active nickel mines in 2004. Imports or recycling met all needs, except limited quantities of byproduct nickel that were recovered at some copper and precious metal refineries. In 2004, Stillwater Mining Company (now majority owned by MMC Norilsk Nickel Group of Russia) shipped 671 t of nickel in crystalline sulfate (Stillwater Mining Company, 2005a, p. 1-7; b, p. 7-19). The company has been mining PGEs and gold since 1986 from the Stillwater Complex at Nye in Montana's Beartooth Mountains. The ore is associated with the 45-km-long J-M reef. The company's two mills (Nye and East Boulder, MT) together processed 1.15 Mt of ore and subgrade material in 2004, with a combined mill head grade of 17 grams per metric ton (g/t) palladium and platinum. About 71% of the PGEs came from the Stillwater Mine at the eastern end of the reef; the remaining 29% came from the new East Boulder Mine, where the company was gradually increasing ore production to 1,500 t/d. Concentrates from the two mills were being trucked to the company's smelting and refining complex at Columbus, MT, where a palladium- and platinum-rich filter cake containing 50% to 55% PGEs by weight was produced. The crystalline nickel sulfate is a refinery byproduct and contains minor amounts of cobalt.

ASARCO LLC (a wholly owned subsidiary of Grupo México, S.A. de C.V.) also produced limited quantities of byproduct nickel sulfate at its Amarillo copper refinery in Texas.

Limited tonnages of primary nickel are recovered during the refining of some crude oils where it occurs as porphyrins or other organometallic compounds. The nickel content of crude oil is quite variable and reflects several factors, such as density of the oil, the sulfur content of the oil, the field location, geologic occurrence, and geologic age. The nickel is concentrated in (1) flexicoke and other petroleum refinery residues, (2) fly ash, ash sludge, slag, and boiler scale produced at oil-fired powerplants, and (3) spent petroleum refinery catalysts.

Secondary Production.—International Metals Reclamation Company Inc. (a subsidiary of Inco Limited) continued to produce nickel-chromium-iron remelt alloy at its metals recovery facility in Ellwood City, PA. Feed materials included chromium and nickel wastes generated by the stainless steel industry; filter cakes, solutions, and sludges from the plating industry; refractory brick; spent catalysts; and spent nickel-base batteries. The batteries range in size from small nickel-cadmium (NiCd) and nickel-metal hydride (NiMH) household batteries to industrial-size batteries used to provide backup power in emergencies.

Spent catalysts are another U.S. source of nickel. Nickel, incorporated into the structure of some catalysts (such as nickel molybdate), can be recovered when the spent catalyst is autoclaved and separated from its carrier. In 2004, CS Metals of Louisiana, LLC recovered nickel from spent catalysts at its reclamation facility on the Mississippi River at Convent, LA. However, at yearend, CS Metals' parent company (CRI Metal Products, Inc. of Houston, TX) decided to cease reclamation operations at Convent and focus instead on catalyst manufacturing. The $80 million facility, commissioned in October 2000, had the capacity to produce 2,300 t/yr of

contained nickel in the form of a nickel-cobalt byproduct. The bulk of the spent catalysts had come from oil refining and petrochemical operations. CRI Metal Products, a wholly owned member of the Royal Dutch/Shell Group of companies, made the decision after the Shell Chemicals segment announced that it was divesting its global catalyst regeneration business (Royal Dutch Petroleum Company, 2005, p. 31, 64).

Gulf Chemical and Metallurgical Corp. of Freeport, TX, also processed spent catalysts in 2004. The Freeport facility can treat nickel/molybdenum and cobalt/molybdenum hydrotreating catalysts that have been "poisoned" by nickel and vanadium. Gulf Chemical converts the byproduct nickel residue to a crude nickel-cobalt alloy in an electric furnace, and then sells the alloy to nickel refineries.

Consumption

In 2004, world demand for primary nickel was at an alltime high, with most nickel producers operating at full capacity. Primary nickel demand in the Western World was reported to be 1.05 Mt, slightly less than the revised recordbreaking figure of 1.06 Mt for 2003 (International Nickel Study Group, 2005). Demand was buoyed by spiraling apparent consumption in China, which has risen to 150,800 t from 43,400 t in 1999. China was expected to be the second ranked consumer of primary nickel in 2006, after the European Union (Eramet Group, 2005, appendix p. 22, 38).

U.S. apparent consumption of primary nickel was 129,000 t, or about 12% of Western demand. U.S. industry reported consumption of an additional 83,300 t of nickel in scrap. Within the United States, the share of primary nickel consumed in the production of stainless and alloy steels decreased to 47% in 2004 from 50% (revised) in 2003. The new meltshop of North American Stainless (NAS) at Ghent, KY, produced 691,000 t of stainless steel slabs—28% more than that of the previous year. NAS, which started up in 2002, is a wholly owned subsidiary of Acerinox, S.A. of Madrid, Spain—the third ranked stainless steel producer in the world (Acerinox, S.A., 2005, p. 82-83).

U.S. demand for most nonferrous alloys remained weak. Markets for copper-nickel alloys were especially hard hit in 2003, but began to recover in 2004. Demand for superalloys—key fabrication materials for jet engines—increased by 17% in spite of the financial difficulties of many commercial airlines. Robust sales to the defense sector partially offset low growth in the civil aircraft market (Napier, 2005).

The estimated value of apparent primary nickel consumption in the United States was $1.78 billion, up from $1.13 billion in 2003—an increase of 58%. Apparent primary consumption increased 10% to 129,000 t from 117,000 t. The 58% increase in the value of primary consumption resulted because of the combined effect of a 44% increase in the London Metal Exchange (LME) cash price and a moderate increase in primary consumption. Apparent primary consumption plus reported secondary consumption totaled 212,000 t.

Stainless Steel and Low-Alloy Steels.—In 2004, the U.S. and world demand for nickel continued to be driven by the stainless steel industry. Stainless steel producers accounted for 44% of primary nickel demand in the United States and more than 60% of primary demand in the world. Production of raw stainless steel (excluding production in China, Eastern Europe, and the Commonwealth of Independent States) has almost doubled in the past 10 years, growing to 22.08 Mt in 2004 from 13.16 Mt in 1994 (Inco Limited, 2006, p. 4). This equates to a compound annual growth rate of 5.3% for the 10-year period. A large part of this growth was in India, the Republic of Korea, and Taiwan. Additional melt capacity was being brought onstream in Asia to accommodate the projected growth in demand for stainless steel after 2006. There also has been a shift to increasingly larger meltshops, with seven stainless steel companies now having meltshops with capacities larger than 900,000 t/yr. In April, Baosteel Group commissioned a 750,000-t/yr meltshop at its No. 1 works in Shanghai, China. Since 2001, China has consumed more stainless steel than any other country. China had an apparent consumption of 4.72 Mt of stainless steel in 2004, with state-owned mills producing 1.32 Mt. Chinese imports of stainless steel totaled 2.90 Mt; exports, 0.34 Mt (Inco Limited, 2006, p. 31).

Production of raw stainless steel and heat-resisting steel in the United States totaled 2.40 Mt in 2004, up 8% from 2.22 Mt in 2003. This tonnage was the highest annual production ever recorded for the United States. Nickel-bearing grades accounted for 1.55 Mt or 64% of the total stainless steel production (American Iron and Steel Institute, 2005a, p. 75-76; b).

The North American stainless steel industry continued to consolidate. On June 1, Allegheny Technologies Inc. (ATI) bought J&L Specialty Steel, LLC from Arcelor, S.A. (J&L Specialty Steel, LLC, 2004). J&L manufactured flat-rolled stainless steel products and had plants in Midland, PA, and Louisville, OH. ATI was in the process of integrating J&L's operations with those of its own steelmaking subsidiary, Allegheny Ludlum Corporation. Allegheny Ludlum is a leading U.S. producer of stainless steel plate, sheet, and strip, with a meltshop and other major steelmaking operations at Brackenridge, PA. The integration raised Allegheny Ludlum stainless steelmaking capacity by 15% to 20% (an increase of about 270,000 t/yr of slab) and allowed Allegheny Ludlum to better utilize its hot-rolling mill at Brackenridge (Allegheny Technologies Inc., 2004).

Superalloys and Related Nickel-Base Alloys.—About 28% of the primary nickel consumed in the United States was used to make high-performance superalloys and related nickel-base alloys for the aerospace, electric power, and petrochemical industries. U.S. production of superalloys was up 12% from that of 2003 because of improved sales to manufacturers of jet aircraft engines. Sales of military aircraft increased by 15%; sales of missiles, by 10%. For the first time in 2 years, the number of U.S. commercial jetliners delivered increased, going up 4 planes to 285 (Douglass, 2005§).

Nickel-Base Batteries.—U.S. demand for nickel in rechargeable batteries continued to increase. U.S. imports of nickel-base batteries from China and Japan have been steadily growing since 1998 when General Motors Corporation introduced its pure electric EV_1 in the United States, and Toyota Motor Corporation began manufacturing its Prius hybrid electric vehicle (HEV) in Japan. In 2004, most of the newer HEVs on U.S. highways were using NiMH batteries to store the energy recovered from the vehicle's regenerative braking circuitry—a system that reduces overall fuel consumption.

Most battery manufacturers were using either sintered electrodes or pasted foam electrodes in NiMH cell production (Wasmund, 2005). The sintered electrode is made by sintering filamentary nickel powder onto both sides of a perforated, nickel-coated steel strip or pure nickel screen. A proprietary active material is then added by chemical or electrochemical impregnation. The second type of electrode is formed by pasting nickel hydroxide into nickel foam (a nickel skeleton structure that resembles an air filter made of aluminum or stainless steel). The bulk of the nickel foam entering the market place was being used to fabricate positive electrode substrates for rechargeable batteries. However, some foam was being used as catalyst substrates or as high-temperature, corrosion-resistant filters.

Electric and Hybrid Electric Vehicles.—Growing HEV sales in North America increased demand for nickel foam and specialty nickel metal powders, key NiMH battery components. Between 1999 and mid-2004, more than 140,000 hybrid vehicles were sold in the United States. Toyota Motor Corporation has produced more than 120,000 Prius sedans worldwide since 1997 and was preparing to manufacture 300,000 units per year at its plants in Japan (Hybrid & Electric Vehicle Progress, 2005).

Stocks

On December 31, U.S. consumer stocks of primary nickel totaled 5,530 t—15% more than the 4,800 t (revised) at yearend 2003. Stocks in LME warehouses dropped sharply during the summer of 2004, bottoming out at 8,394 t on June 30—the lowest level reported in more than 7 years. LME stocks, however, quickly built up again and ended the year at 20,898 t—13% less than the 24,072 t reported at the end of 2003. Data collected by the International Nickel Study Group indicated that, at yearend 2004, world nickel producers (excluding those in Austria, China, Macedonia, Serbia, and the Ural area of Russia) had approximately 101,400 t of nickel in primary products in stock. About 73% or 74,000 t of the producer material was Class I materials—refined products with a nickel content of 99% or greater (electrolytic cathode, briquets, pellets, powder, rondelles, etc., in order of decreasing production). All stocks in LME warehouses are Class I. Class II materials include ferronickel, oxide sinter, and East Asian utility nickel—products with a nickel content less than 99% (International Nickel Study Group, 2005).

Prices

The January 2004 average cash price for 99.8% pure metal on the LME was $15,327 per metric ton ($6.952 per pound)—the high point for the year and the highest monthly average since March 1989. Nickel prices weakened during the spring, with the monthly average bottoming out in May at $11,118 per ton ($5.043 per pound). Prices vacillated during the summer and fall and eventually recovered in December to $13,769 per ton ($6.245 per pound). The average annual price was $13,823 per ton ($6.270 per pound)—44% greater than the 2003 average.

World Industry Structure

The world's leading nickel producer was MMC Norilsk Nickel Group of Russia, followed by Inco of Canada. Other major producers were BHP Billiton Plc of the United Kingdom, Eramet Group of France, Falconbridge Limited of Canada, and WMC Resources Ltd. of Australia. The nickel industry has responded to the recent price volatility by becoming more competitive through corporate alliances and making technological advances in extractive metallurgy.

In an era of growing global nickel demand, several Chinese companies have moved to secure future supplies to meet significant projected growth in demand for nickel on the Asian mainland. Chinese companies were negotiating supply contracts, acquisitions and joint ventures with mining companies in several key nickel-rich countries, including Australia, Canada, Cuba, and Papua New Guinea.

In September, China Minmetals Corporation offered to buy Noranda Inc., a major Canadian mining company. At the time, Noranda owned almost 59% of Falconbridge, the third ranked producer of refined nickel in the world, with key operations in Canada, the Dominican Republic, and Norway. In 2004, Falconbridge produced 100,887 t of refined nickel products—3% less than the record high of 104,410 t set by the company in 2003, but still about 8% of world supply. Minmetals was in the process of transforming itself from a trading-oriented organization into a broadly based resource company. Noranda executives eventually rejected the Chinese offer and, in a dramatic turnaround, agreed to be taken over by Falconbridge (Noranda Inc., 2004; Falconbridge Limited, 2005a, p. 87-89; b).

World Review

Australia.—Australia was the third ranked nickel-producing country in the world and was beginning to rival Canada. Most of the nickel properties under development are in the State of Western Australia. WMC was still the leading nickel producer in Western Australia, recovering 115,774 t of nickel in sulfide concentrate in calendar year 2004, down slightly from 117,722 t in 2003. The slippage in output may be misleading because the company was in the process of expanding the large open pit mine at Mount Keith and commissioning the new 11 Mile Well open pit (WMC Resources Ltd., 2005a, p. 22-23).

Laterite Operations.—Three nickel laterite mining and processing operations have been commissioned in the Kambalda-Goldfields region since 1998—Bulong, Cawse, and Murrin Murrin. Combined, the three will probably add about 60,000 t/yr of nickel to world production capacity. In fiscal year 2004, Murrin Murrin, the largest of the three, produced 28,682 t of nickel and 2,072 t of cobalt, up from 27,683 t of nickel and 1,867 t of cobalt in fiscal year 2003. Murrin Murrin is a joint venture of Minara Resources Limited (60% interest) and Glencore International AG (40%) (Minara Resources Limited, 2004, p. 21-24).

BHP Billiton began developing its Ravensthorpe project in Western Australia and was increasing production capacity at its Yabulu nickel-cobalt refinery near Townsville, Queensland, to accommodate the output from Ravensthorpe. When the Ravensthorpe/Yabulu project is completed, BHP Billiton would become the third ranked nickel producer in the world after Norilsk Nickel and Inco. The capital cost of the integrated project was expected to be about $1.4 billion. Of the $1.4

billion, about $1.0 billion would be required to develop the first of Ravensthorpe's three deposits and to build an onsite ore treatment facility (BHP Billiton Plc, 2004). The remaining $350 million would be used to expand the Yabulu refinery, extending the life of the refinery by 25 years. The additional production could be available by yearend 2007. Yabulu will continue to process lateritic ores from other parts of the Asia-Pacific region. Since 1986, Yabulu has imported some 43 Mt of ore from Indonesia, New Caledonia, and the Philippines. When the expansion is completed, Yabulu will be able to produce 76,000 t/yr of nickel and 3,500 t/yr of cobalt.

The Ravensthorpe minesite is about 45 km inland from Western Australia's Southern Coast and about 155 km west of the port of Esperance. About $85 million has been spent on the project since 1998 for testwork and feasibility studies. Limited site activities began in May 2004. The treatment plant will have two separate processing circuits—one for the iron-rich, high silica limonitic ores, and one for the underlying magnesium-rich saprolitic ores. The limonitic ores will be crushed, scrubbed, cycloned, and subsequently screened to remove unwanted, barren silica. The nickel and cobalt then will be recovered from the upgraded limonite by pressure acid leaching (PAL). The saprolitic ores will beneficiated in a similar manner, but the nickel and cobalt will be recovered by atmospheric leaching. The saprolitic ore will be leached with a mixture of the PAL discharge and additional acid. Ravensthorpe is being designed to produce up to 220,000 t/yr of mixed nickel and cobalt hydroxide intermediate product.

Sulfide Operations.—WMC was expanding production capacity at its mining, smelting, and refining operations in Western Australia in response to strengthening nickel prices. WMC's refinery at Kwinana produced 62,500 t of nickel metal, up from 61,400 t in 2003. The company's smelter near Kalgoorlie produced 97,780 t of nickel in matte, down slightly from 99,152 t in 2003, with one-third of the matte being exported. More than 45% of the concentrate for the smelter came from the company's Mount Keith deposit in the Northern Goldfields region. The other 55% came from Leinster and third party mines at Kambalda. The Mount Keith operation demonstrates that large tonnage, low-grade nickel deposits can be mined successfully. According to WMC, Mount Keith has an estimated 260 Mt of proven and probable ore reserves (excluding stockpiles) averaging 0.52% nickel plus 177 Mt of additional resources averaging 0.55% nickel. WMC continued to evaluate Yakabindie, another low-grade deposit 25 km south of Mount Keith. The Yakabindie deposit, acquired in early 2001, contains an estimated 289 Mt of resources averaging 0.58% nickel (WMC Resources Ltd., 2005a, p. 22-23, 76-78).

Canada.—Key events of 2004 are summarized in the nickel chapter of the Canadian Minerals Yearbook (Bill McCutcheon, Senior Commodity Advisor, Natural Resources Canada, written commun. and unpub. data, 2005).

Manitoba and Nunavut.—Inco's operations at Thompson produced 53,000 t of refined nickel in 2004, setting a refinery production record for electrolytic nickel (Inco Limited, 2005, p. 2-7). Declining mine production at Thompson was offset by imports of nickel concentrate from Australia.

In 2002, Donner Minerals Ltd. (the predecessor of Donner Metals Ltd.) entered into an agreement with Falconbridge to help explore for nickel in northern Manitoba. Under the agreement, Donner could earn a 50% interest in Falconbridge's Stephens Lake project by spending Can$5 million on the project before the end of 2006. The 3,700-km^2 Stephens Lake property, located on the northwest boundary of the Superior Craton, is almost completely covered by glacial till. In the exploration model, the Stephens Lake area was interpreted as an extension of the Thompson nickel belt (Donner Minerals Ltd., 2002, p. 11-13; 2003). In February 2003, Donner and Falconbridge began drilling selected magnetic and conductive anomalies. None of the drill holes intersected ultramafic rocks, and all conductors were attributed to graphite, iron sulfides, or iron oxides. After drilling 10 holes, the two companies decided to shift exploration efforts further north to Nunavut (Donner Minerals Ltd., 2004b).

In June 2004, Donner signed a similar agreement with Falconbridge to explore the Rainbow property, encompassing 180 km^2 of claims in Nunavut. The Rainbow property is 240 km west of Hudson Bay and 380 km northwest of Churchill, Manitoba. During the second half of the year, the two companies staked 145 km^2 of claims adjacent to the Rainbow property. Six holes were drilled during the 2004 program, four of which intersected disseminated magmatic sulfides with nickel grades less than 0.5%. A fifth hole intersected gold mineralization. Several boulder samples collected from the central area of the property contained massive or disseminated nickel sulfides (Donner Minerals Ltd., 2004a).

Newfoundland and Labrador.—Since 2002, Inco and its subsidiary (Voisey's Bay Nickel Company Limited) have passed several milestones in the first phase of the three-phase Voisey's Bay nickel-copper-cobalt project. Inco does not expect to complete the project before 2018 (Hand and Jones, 2004). Inco began infrastructure work in 2003 after SNC Lavalin completed a bankable feasibility study of the mine, concentrator, and related facilities. Construction of the open pit mine and 6,000-t/d concentrator was expected to cost between $528 million and $582 million.

Ontario.—Additional reserves were being developed in the Sudbury Igneous Complex of east-central Ontario. Several exploration projects were also underway, particularly in and around some older, largely depleted mines. More than 11 Mt of nickel have been recovered from the Sudbury District since the initial discovery in 1883. The bulk of the sulfide ores occur along the base of the igneous complex as complicated mixtures of sulfide assemblages, xenoliths, and impact breccias. The principal sulfide minerals are, in order of decreasing abundance, pyrrhotite, pentlandite, chalcopyrite, pyrite, and bornite. The copper content of the typical Sudbury ore approximately equals the nickel content. In 2004, the Sudbury operations of Falconbridge processed 2.26 Mt of local ores with an average grade of 1.31% nickel and 1.28% copper (Falconbridge Limited, 2005a, p. 30). Inco, Sudbury's other principal nickel producer, had equivalent ore grades of 1.24% nickel and 1.34% copper. Inco's Copper Cliff refinery produced a record-high 61,000 t of finished nickel (Inco Limited, 2005, p. 2-14).

Falconbridge completed development of its Montcalm nickel-copper deposit near Timmins in northern Ontario. The company's board of directors approved the project in 2003. Since then, the company had spent more than Can$77 million on the Montcalm Mine, which was expected to ship 750,000 t/yr of ore during

the next 7 years. Company officials estimated that the project's capital investment costs would be about Can$142 million. In the fourth quarter of 2004, the new mine shipped 220,000 t of ore averaging 1.32% nickel to the company's Kidd mill, where 2,152 t of nickel in concentrate was recovered. The Montcalm operation was expected to produce 9,000 t of nickel in concentrate in 2005. According to Falconbridge, Montcalm has 4.88 Mt of proven and probable reserves averaging 1.51% nickel and 0.73% copper. Montcalm also has 0.70 Mt of inferred resources averaging 1.7% nickel (Falconbridge Limited, 2005a, p. 13, 22).

Quebec.—More than 20 companies were actively exploring for copper, nickel, and PGEs in the Nunavik region of northern Quebec. Exploration of the Proterozoic Cape Smith fold belt has accelerated since 2003 owing to high nickel prices, the continuing success of the new Raglan Mine near Katinniq, and the discovery of sulfide mineralization west of Lac Chukotat. Canadian Royalties Inc., Cascadia International Resources Inc., Goldbrook Ventures Inc., Knight Resources Ltd., and Novawest Resources Inc. were drilling pyroxenite and peridotite complexes within the fold belt.

Falconbridge commissioned its Raglan Mine in the central part of the belt in 1997. In 2004, Raglan produced 26,552 t of nickel in concentrate, 6% more than was recovered in 2003. At yearend 2004, Raglan had 15.7 Mt of proven and probable reserves, averaging 2.82% nickel and 0.78% copper. Falconbridge was increasing the capacity of the Raglan mill by 5,000 t/yr of nickel (Falconbridge Limited, 2005a, p. 22, 30).

In 2001, Canadian Royalties optioned the Expo-Ungava property from Ungava Minerals Inc. and launched a Can$1.25 million exploration program. Later that summer, Canadian Royalties discovered the TK nickel-copper-PGE deposit south of Lac du Bombardier. Each year since 2001, the company has sharply increased its exploration funding. The expanded program, known as the Raglan South Trend Nickel Project, led to the discovery of the Mesamax deposit in 2002 and the Lac Mequillon deposit in 2003. The deposit at Lac Mequillon has an inferred resource of 1.4 Mt grading 0.7% nickel and 0.9% copper, with PGE, gold, and cobalt credits (Whyte, 2004). The Expo-Ungava property consists of more than 1,400 km^2 of claims, of which the most promising have been the Expo and Mesamax deposits. In 2004, one of Canadian Royalties' drill holes intersected an ultramafic body northeast of and stratigraphically below the ultramafic body that hosts the Expo deposit. Disseminated and massive sulfides were found at depths of 96 to 120 m (Canadian Royalties Inc., 2004).

In 2003, Knight Resources Ltd. associated with Anglo American Exploration (Canada) Ltd. to explore a 720-km^2 area, 90 km west of the Raglan property line. Knight Resources drilled 16 holes in an area where numerous boulders with sulfide mineralization were discovered. In 2004, the company spent Can$4.4 million evaluating a 3-km by 1-km tract now known as the Greater Frontier area. An additional 60 holes were drilled during the 2004 field season, many of which intersected disseminated nickel sulfides (Knight Resources Ltd., 2004a; b).

China.—Chinese demand for nickel has risen dramatically since 1999. Demand for primary forms of nickel was estimated to have reached 144,000 t in 2004, 12% more than in 2003 (Eramet Group, 2005, appendix p. 38). Demand weakened slightly in the first half of the year, but, towards yearend, resumed its upward movement despite a hike in benchmark interest rates by the People's Bank of China (PBOC) on October 29. Chinese demand for stainless steel and nickel could be negatively affected if the PBOC raises interest rates further in a move to slow the country's burgeoning economy. The Chinese stainless steel industry currently accounts for about 46% of the country's primary nickel demand. Chinese production of stainless steel increased more than fivefold between 1999 and 2004. China was the world's leading consumer of stainless steel in 2004, accounting for almost 20% of world stainless steel consumption. The country had at least eight melt shop expansions or greenfield projects underway. Taiyuan Iron & Steel (Group) Company Ltd. (TISCO) accounted for 55% of state-owned stainless steel production and was planning to make more than 920,000 t of stainless steel in 2005 (Inco Limited, 2006, p. 4, 31).

China has a large electroplating industry and a number of rechargeable battery manufacturers that use nickel. China's plating industry accounted for about 31% of the country's primary nickel demand in 2004 (Eramet Group, 2005, appendix p. 38). Several Chinese companies have greenfield joint ventures with foreign nickel suppliers, including the Kunshun nickel chemical plant near Shanghai and a state-of-the-art nickel foam project underway at Dalian.

In November, Jinchuan Group Ltd. and WMC Resources Ltd. formed a joint-venture company to explore for copper and nickel in Gansu and other western provinces of China. WMC already has two contracts to supply Jinchuan—China's leading nickel producer—with a total of 120,000 t of nickel-in-matte from its Kalgoorlie smelter between 2005 and 2010 (WMC Resources Ltd., 2004).

In 2003, Inco formed a joint venture with a Chinese developer to produce large volumes of high-quality nickel foam for the world market. The partners in the Chinese foam venture were Inco Asia Holdings (a subsidiary of Inco), Liaoning Wanzhong Real Property Development (a developer based in Dalian, China), and Korea Nickel Corp. (a Republic of Korea producer of utility nickel in which Inco had a 25% equity interest). The new company was named Inco Wanzhong Advanced Technology Materials (Dalian) Ltd.

The Inco joint venture constructed a state-of-the-art nickel foam production plant in Dalian, a port on the Liaotung Peninsula. The foam plant, which became fully operational in 2005, was designed to produce 2 million square meters per year of nickel foam. Inco agreed to invest $10 million in the startup phase of the project (Inco Limited, 2003). The nickel foam is produced using electroplating technology licensed from the Harbin Institute of Technology in Heilongjiang Province. The bulk of the foam is sold to manufacturers of rechargeable batteries. Most of the batteries will be used to meet growing demand in China, Japan, the Republic of Korea, and Taiwan. The Dalian plant complements Inco's existing foam production facilities at Clydach, Wales, United Kingdom. The foam produced at Dalian, however, has some different characteristics than the foam produced at Clydach. The nickel metal feed at Clydach is produced onsite by the carbonyl process, a gaseous vaporization purification process. The two types of foams supplement specialty nickel metal powders being sold by Inco to battery manufacturers.

Cuba.—China and Venezuela agreed to help Cuba expand and further modernize the island's nickel industry. In November, China agreed to participate in a new joint venture that would salvage the partially completed mining complex at Las Camariocas. China was to invest $500 million in the venture and was considering investing an additional $1.3 billion to develop a large laterite deposit in Camaguey Province. It may be possible to convert the unfinished ammonia leach operation at Las Camariocas to ferronickel production, but the construction site near Moa has been idle for more than a decade. Cubaniquel, the state-owned monopoly, would have a 51% interest in the Las Camariocas project, while Minmetals would have a 49% interest. Construction of a greenfield mine and plant at San Felipe (Camaguey Province) or at Pinares de Mayari West (Holguin Province) could easily use the entire $500 million (Rodriguez, 2004). Las Camariocas would produce 22,500 t/yr of nickel; the Camaguey complex, 50,000 t/yr of nickel. As part of the agreement, Cuba would supply China with 4,000 t/yr of nickel from 2005 to 2009. Cuba would retain 51% ownership in future base-metal companies created with Chinese capital.

In December, the presidents of Cuba and Venezuela reaffirmed their 2000 trade accords and signed two new economic agreements. Part of the new nickel production would be shipped to stainless steel plants in coastal China, with the rest going to a greenfield stainless steel plant proposed for the Guayana region of Venezuela. Because Venezuela is a leading exporter of iron ore and direct reduced iron, the proposed steel plant is expected to have no difficulty obtaining iron (Reuters Limited, 2004§).

Metals Enterprise (a joint venture of Sherritt International Corporation and the Government of Cuba) considered expanding its pressure acid leaching complex at Moa. The plant is currently capable of producing 33,000 t/yr of nickel plus cobalt in mixed sulfides. In March 2005, Sherritt and its Cuban partner agreed to increase the production capacity at Moa to 49,000 t/yr. The $450 million expansion was scheduled to be completed by yearend 2007 (Sherritt International Corporation, 2005§). If successful, the expansion and the two previously mentioned greenfield projects will probably more than double Cuban nickel production to 150,000 t/yr from its current level of 74,000 t/yr.

New Caledonia.—At the beginning of 2004, the Goro project was still on hold despite high nickel prices. Inco suspended development work on the laterite mining and processing complex because of escalating costs in 2002. Work was halted after the project's capital costs were forecast to rise above $2.1 billion—$700 million more than the original estimate.

The Goro project underwent extensive review and redesign between January 2003 and April 2004. The design of the hydrometallurgical processing complex was simplified, reducing construction cost estimates by $500 million. The updated capital cost estimate for the mine, processing plant, and infrastructure was $1.88 billion. The Government of France agreed to finance $350 million of the project's direct costs. France will also provide financing to help build a power generation station needed by Goro. Goro Nickel S.A. (the project company) and Inco completed financing arrangements with the Government of France. Tax advantages under the Girardin Act will probably generate $130 million in cash benefits for the project.

The final decision to restart the project was made in October. Goro could begin producing cobalt and nickel by late 2007. The plant would have a nameplate capacity of 60,000 t/yr of nickel, with ramp up to full capacity expected to take 3 years. The capacity of the redesigned plant is 9% greater than the 55,000 t/yr estimated for the previous design. Goro has exceptionally large reserves, allowing the operation to be incrementally expanded over time. Inco's geologists estimated that Goro had 95 Mt of proven and probable reserves averaging 1.53% nickel and 0.12% cobalt. Inco also identified 55 Mt of additional resources (Hand, 2004; Inco Limited, 2005, p. 6-14).

At yearend, Inco had an 85% interest in the project, with the Government of France's Bureau de Recherches Géologiques et Minières holding the remaining 15%. However, a consortium of Japanese companies led by Sumitomo Metal Mining Co., Ltd. was interested in acquiring a 20% to 25% interest in Goro. Inco also was considering giving the three provinces of New Caledonia a 10% share in the project (Inco Limited, 2005, p. 6).

Papua New Guinea.—In February, China Metallurgical Construction (Group) Corporation (MMC), a company owned by the Government of China, signed a preliminary agreement with Highlands Pacific Limited of Australia to develop the Ramu nickel project in Madang Province of Papua New Guinea. MCC would acquire an 85% interest in the $650 million project. Highlands Pacific had a 68.5% interest in the Ramu project, while Mineral Resources Development Company, a unit of the Papua New Guinea Government, had the remaining 31.5%. Neither of the existing stakeholders would be required to put any new investment into the project (Reuters Limited, 2004).

The Ramu project has 42 Mt of measured resources averaging 0.93% nickel and 0.11% cobalt plus 30 Mt of indicated resources averaging 1.07% nickel and 0.11% cobalt, using a cutoff grade of 0.5% nickel. The proposed laterite mining complex would produce 33,000 t/yr of nickel and 3,200 t/yr of cobalt either as metal or contained in a high-grade intermediate product for sale to a suitable smelter or refiner (Highlands Pacific Limited, 2004§).

Philippines.—Coral Bay Nickel Corporation (CBNC) was constructing a $180-million hydrometallurgical processing plant near Bataraza on the island of Palawan. The project, launched in April 2002, was a joint venture of Sumitomo Metal Mining Company, Ltd. (SMM) (54%), Mitsui & Co., Ltd. (18%), Sojitz Corporation (18%), and a Philippine company, Rio Tuba Nickel Mining Corporation (10%). The CBNC facility was designed to produce 10,000 t/yr of nickel and 700 t/yr of cobalt as a mixed sulfide precipitate (Balitang Malacañang Office of the Press Secretary, 2005b§). Trial runs with the plant circuitry began in September 2004, with the first shipment of precipitate planned for 2005 (Sumitomo Metal Mining Co., Ltd., 2004).

The CBNC plant was designed to extract nickel from low-grade ores previously considered waste. Feed was coming from stockpiles of low-grade ore at the adjacent Rio Tuba Mine. The mine, an open pit laterite operation, had been producing direct shipping ore for Japan since 1976. The mine stockpiled its lower-grade ores for approximately 20 years, accumulating 16 Mt of ore suitable for processing. The stockpiled material and future production of similar material will provide CBNC with about 35 Mt of ore on a wet basis during the next 25 years (Go,

2004§).

All the precipitate was being exported to Japan, where the two metals were separated at SMM's Niihama refinery in Ehime prefecture. At Niihama, SMM uses matte chlorine leach electrowinning technology to produce electrolytic cobalt and electrolytic nickel.

The Philippines reportedly has the third ranked resources of nickel laterite in the world, after Cuba and Indonesia. According to CNBC officials, preliminary studies indicate that the ophiolite belts of the Philippines have extensive nickel resources aside from those on Palawan. These resources include deposits on the islands of Mindoro, Negros, Samar, as well as those in the Provinces of Surigao del Norte (Mindanao) and Zambales (western Luzon). CBNC has ongoing laterite development projects in Samar and Surigao Provinces in addition to Rio Tuba (Balitang Malacañang Office of the Press Secretary, 2005a§).

Russia.—Norilsk Nickel, the world's leading producer of nickel and palladium, continued to play an important role in the economy of Russia. Company analysts estimate that Norilsk Nickel controls at least 19% of world mined nickel production and more than 50% of world mined palladium production. Norilsk Nickel produced 243,000 t of nickel in 2004—about 92% of Russia's total primary nickel output for the year. Production was 2% greater than the 238,800 t (includes tolling) reported for 2003. Norilsk Nickel shipped an additional 7,000 t in 2004 from stocks. Of the 250,000 t shipped, at least 244,000 t (or 98%) was exported. Only 6,000 t, or 2%, was sold to Russian consumers, down from 12,000 t in 2003 (MMC Norilsk Nickel Group, 2005, p. 6, 51; Morozov, 2005).

The Polar Division is responsible for Norilsk Nickel's nickel mining, smelting, and refining operations on the Taimyr Peninsula of Siberia. A second division, Kola MMC, oversees similar operations on the Kola Peninsula. Norilsk Nickel reported that it had total proven and probable reserves of at least 395 Mt on a gross weight basis. The Talnakh ore field on the Taimyr Peninsula alone had 4.95 Mt of nickel contained in 238 Mt of proven and probable reserves averaging 2.08% nickel (MMC Norilsk Nickel Group, 2005, p. 36-39).

In 2003, Norilsk Nickel's directors approved a modernization plan that would ensure sustainability of the two divisions until 2015. This included finishing the renovation of the flash smelters at Nadezhda on the Taimyr Peninsula and bringing the Pelyatka natural gas field into full production. The Polar Division was developing the Skalisty Mine in the Talnakh ore field to replace declining reserves at the Oktyabrsky Mine.

The remaining 8% of Russia's primary nickel output came from independent operations in the Urals region—Rezh Nickel Works JSC in Sverdlovsk Oblast, Ufaleynikel JSC in Chelyabinsk Oblast, and Yuzhuralnikel Combine JSC in Orenburg Oblast.

Spain and Portugal.—In December, Rio Narcea Gold Mines, Ltd. completed development of the Aguablanca open pit nickel-copper-PGE mine. Glencore International AG has agreed to purchase 100% of the nickel sulfide concentrate produced at Aguablanca through the year 2010. The mine-and-mill complex was to be commissioned in 2005 (Rio Narcea Gold Mines, Ltd., 2005, p. 6-8). Fluor Corporation is the prime contractor for the project. The magmatic sulfide ores at Aguablanca occur in a gabbro-norite intrusive complex. The open pit will eventually reach a depth of 250 meters (m) and have a life of more than 10 years. The flotation plant would treat 1.5 million metric tons per year (Mt/yr) of ore. Aguablanca was expected to produce 8,200 t/yr of nickel and 5,000 t/yr of copper in concentrate. The concentrate was expected to average 9% nickel, 7.1% copper, 0.22% cobalt, and 6 g/t PGE. At yearend, the Aguablanca open pit had 15.7 Mt of proven and probable reserves averaging 0.66% nickel, 0.46% copper, and 0.47 g/t PGE. The reserve figures equate to 103,000 t of contained nickel and 72,500 t of contained copper (Rio Narcea Gold Mines, Ltd., 2005, p. 22).

Rio Narcea planned to exploit the deposit's deeper resources within the next 4 years. Contractors began excavating a 3-km-long decline to access higher grade mineralization beneath the open pit and permit exploratory underground drilling. At yearend, the decline had advanced about 1.1 km from the portal. Underground mining was scheduled to begin in mid-2006 (Rio Narcea Gold Mines, Ltd., 2005, p. 3, 6-8).

Besides Aguablanca, Rio Narcea was actively evaluating several other promising nickel properties in the Serra de Ossa (Portugal)-Sierra Morena (Spain) region. The company identified numerous mafic-ultramafic intrusives with potential for nickel sulfide mineralization in Spain's Badajoz Province and part of southeastern Portugal. In 2003, Portugese mining authorities granted Rio Narcea a license to explore two key districts in the Alentejo region bordering Badajoz Province. The license covers a 927-km^2 block in the Campo Maior area and a 993-km^2 block in the Beja area. Outcrops of gossanous troctolite near Elvas in the Campo Maior area assayed up to 0.8% nickel and 0.5% copper. The company drilled 21 holes, totaling 5,100 m, to test targets with coincident geochemical and geophysical anomalies. Fourteen holes were in Spain; seven in Portugal. The results of the 2004 drilling program were encouraging, but the nickel mineralization identified to date has been subeconomic (Rio Narcea Gold Mines, Ltd., 2005, p. 28, 58).

Turkey.—European Nickel PLC (ENickel) (a company headquartered in the United Kingdom) was formed in 2000 to acquire and develop nickel laterite deposits in the Balkans. Much of the initial work involved reevaluating known nickel deposits in Albania that might be amenable to heap leaching with sulfuric acid at atmospheric pressure. ENickel has been evaluating the Caldag laterite deposit in western Turkey since March 2002. In June 2004, the company exercised its option on Caldag and now owns the mining licenses outright. The Caldag deposit is 15 km north of the town of Turgutlu and 75 km northeast of the Port of Izmir. According to the company, the laterite deposit has 38 Mt of resources grading 1.14% nickel and 0.05% cobalt (European Nickel PLC, 2005, p. 6). Caldag is one of a number of subtropical laterites that occur in a broad belt of Jurassic-Lower Cretaceous ophiolite complexes that extends from Serbia southeast through Greece and Turkey to Cyprus and Syria (European Nickel PLC, 2004§).

In July, the Government of Turkey issued an environmental license to the British company, allowing it to begin heap leaching on a trial basis. The Government also gave ENickel a foreign investment certificate that exempts the company from import duties and value added tax (VAT) payments on capital

goods used in the leaching trials. Local residents also approved the project. Three months later, ENickel launched a full bankable feasibility study. The study, scheduled for completion in late 2005, will help the company determine if the project can be scaled up to produce 15,000 t/yr of nickel in a mixed nickel-cobalt hydroxide product. Mining had been underway since 2003, when 40,000 t of ore was shipped to ferronickel smelters in Greece and Macedonia (European Nickel PLC, 2005, p. 5).

In August, ENickel began construction of the first of three pads, each holding 8,000 t of ore. Irrigation of the heaped ore with sulfuric acid began in late September. In November, ENickel announced that tests at its Caldag pilot plant demonstrated that significant nickel could be brought into solution within a few days of the initial irrigation. The pilot plant is now in full operation and producing about 2 t per week of mixed hydroxide (European Nickel PLC, 2004).

ENickel hoped to adapt the technology developed at Caldag to similar deposits in Serbia. The company already has obtained licenses from the Government of Serbia to evaluate the Lipovac and Mokra Gora deposits in the central part of that country (European Nickel PLC, 2005, p. 8-9). In July, BHP Billiton and ENickel signed a series of agreements that included technology sharing. At yearend, BHP Billiton had a 3.5% interest in ENickel.

Current Research and Technology

Scramjets and spaceplanes may provide a future aerospace market for nickel. On November 16, the National Aeronautics and Space Administration (NASA) successfully flew the last of its three X-43A hypersonic aircraft, setting a new speed record for an aircraft powered by an "air-breathing" engine (Gugliotta, 2004a; b). The engine, a scramjet, was constructed primarily from nickel-base superalloys. If the engine is not cooled, temperatures in the combustor will exceed 5,000° F, which is higher than the melting temperature of most metals. The use of nickel-base superalloys combined with good structural design and active cooling allowed the engine to survive these very high temperatures reached in the test flights (Andreadis, 2004).

Engineers designed and built three scramjet aircraft as part of NASA's Hyper-X program. Each aircraft was 3.7 m (12.3 feet) in length and weighed about 1.3 t (Dornheim, 2004). The U.S. Air Force also had a scramjet demonstration program and was exploring the feasibility of developing a hypersonic cruise missile for national defense. The Boeing Company and the Pratt & Whitney business unit of United Technologies Corp. were collaborating with the Air Force on the project. The first tests of the Air Force scramjet were scheduled for late 2008.

Outlook

No primary nickel producer is expected to be operating in the United States before 2015, with the possible exception of Kennecott's proposed underground mine in the Upper Peninsula of Michigan. Grupo México and Stillwater will continue to recover limited amounts of byproduct nickel from precious metals and base-metals refining operations in the western United States. Larger amounts of byproduct nickel also could be generated in Minnesota if PolyMet and/or Teck Cominco Limited decide to proceed with their PGE projects in the west central part of the Duluth Gabbro. Increased byproduct nickel production from North American PGE operations could materialize if current forecasts for fuel cell-battery hybrid vehicles are accurate.

U.S. nickel consumers apparently will be dependent on foreign sources for at least two decades. The ongoing expansion of nickel laterite mining operations in Australia, Cuba, Indonesia, New Caledonia, and the Philippines will help meet the growing demand for nickel worldwide. Laterite projects are also under consideration in Brazil, Cote d'Ivoire, Guatemala, and Kazakhstan. The sulfide concentrate from Inco's state-of-the-art mill and concentrator at Voisey's Bay will help meet the near-term growth in demand projected for nickel.

The world consolidation of nickel operations is expected to continue. On March 8, 2005, BHP Billiton outbid Xstrata plc for control of WMC Resources (WMC Resources Ltd., 2005b, p. 1-9). The acquisition of WMC made BHP Billiton the third ranked producer of nickel in the world, (Platts Metals Week, 2005). Bidding began in October 2004, when Xstrata, a mining group based in Zug, Switzerland, offered to purchase the entire issued share capital of WMC for $A6.35 per share (Xstrata plc, 2004§).

Rising prices for petroleum products have increased demand for hybrid automobiles and with it, NiMH batteries. In the United States, hybrid vehicles were in short supply, reportedly because of the limited availability of NiMH battery packs and the large financial costs associated with scaling up production. The life and replacement cost of the different NiMH battery packs remain important issues (Williams, 2006§).

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TABLE 1
SALIENT NICKEL STATISTICS[1]

(Metric tons of contained nickel, dollars per metric ton, and persons unless otherwise specified)

	2000	2001	2002	2003	2004
United States:					
Mine production	--	--	--	--	--
Plant production	--	--	--	--	--
Secondary recovery from purchased scrap:					
From ferrous scrap	74,300 r	69,300 r	74,900 r	74,000 r	73,500
From nonferrous scrap	12,200	11,900	9,060	9,510 r	9,780
Shipments of purchased scrap[2]	126,000 r	121,000 r	114,000 r	119,000 r	113,000
Exports:					
Primary	8,150	8,450	6,520	6,330	8,000
Secondary	49,900	48,600	39,400	47,300	48,300
Imports for consumption:					
Ore	--	--	--	--	--
Primary	156,000	136,000	121,000	125,000	136,000
Secondary	10,700	8,760	9,110	11,500	18,800
Consumption:					
Reported:					
Primary	115,000	98,800	88,200 r	87,300 r	98,800
Secondary, purchased scrap[3]	86,500 r	81,200 r	83,900 r	83,500 r	83,300
Total	201,000 r	180,000 r	172,000 r	171,000 r	182,000
Apparent:					
Primary	147,000	129,000	121,000	117,000 r	129,000
Secondary, purchased scrap[4]	44,000 r	41,800 r	54,600 r	48,400 r	54,900
Total	191,000 r	171,000 r	175,000 r	165,000 r	183,000
Apparent primary plus reported secondary	233,000 r	210,000 r	205,000 r	200,000 r	212,000
Stocks, yearend:					
Government	--	--	--	--	--
Producers and traders	12,300	12,600	6,150	8,040 r	6,580
Consumer, primary	6,540 r	4,500	4,520 r	4,800 r	5,530
Consumer, secondary	8,380 r	7,980 r	7,040 r	6,270 r	5,210
Total	27,200 r	25,100 r	17,700 r	19,100 r	17,300
Employment, yearend:					
Mine	1	--	--	--	--
Smelter	(5)	--	--	--	--
Port facility	--	--	--	--	--
Price, cash, London Metal Exchange:					
Average annual	8,638	5,945	6,772	9,629	13,823
Average annual dollars per pound	3.918	2.696	3.072	4.368	6.270
Price, 18/8 stainless steel scrap, gross weight:[6]					
Average annual	811	623	692	927	1,450
Average annual dollars per long ton	824	633	703	942	1,473
World, mine production	1,290,000	1,340,000 r	1,350,000	1,390,000 r	1,390,000 e

See footnotes at end of table.

TABLE 1—Continued
SALIENT NICKEL STATISTICS[1]

[e]Estimated. [r]Revised. -- Zero.
[1]Data are rounded to no more than three significant digits; except prices; may not add to totals shown.
[2]Defined as scrap receipts less shipments by consumers plus exports minus imports plus adjustments for consumer stock changes.
[3]More nearly represents amount consumed than does apparent secondary consumption.
[4]Internal evaluation indicates that apparent secondary consumption is considerably understated.
[5]The smelter at Riddle, OR, was decommissioned in 2000.
[6]Derived from the average of the Friday consumer buying price range for 18% chromium-8% nickel scrap in bundles, solids, and clips, Pittsburgh, PA, in American Metal Market.

TABLE 2
NICKEL RECOVERED IN THE UNITED STATES FROM PURCHASED SCRAP
BY KIND AND FORM OF RECOVERY[1]

(Metric tons of contained nickel)

	2003	2004
Kind of scrap:		
Aluminum-base[2]	2,840	2,960
Copper-base	2,140 [r]	2,580
Ferrous-base[3]	74,000 [r]	73,500
Nickel-base	4,530 [r]	4,240
Total	83,500 [r]	83,300
Form of recovery:		
Aluminum-base alloys	2,840	2,960
Copper-base alloys	3,120 [r]	3,990
Ferrous alloys	74,000 [r]	73,500
Nickel-base alloys	3,550 [r]	2,770
Miscellaneous and unspecified	2 [r]	49
Total	83,500 [r]	83,300

[r]Revised.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Primarily borings and turnings of wrought alloys, such as 2218, 2618, 4032, and 8280, or special casting alloys, such as 203.0.
[3]Primarily stainless and alloy steel scrap consumed at steel mills and foundries.

TABLE 3
REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM[1]

(Metric tons of contained nickel)

Form	2003	2004
Primary:		
Metal	70,800 [r]	78,900
Ferronickel	13,700	12,800
Oxide and oxide sinter[2]	146	222
Chemicals	1,820 [r]	5,860
Other	860 [r]	1,010
Total	87,300 [r]	98,800
Secondary, scrap[3]	83,500 [r]	83,300
Grand total	171,000 [r]	182,000

[r]Revised.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes chemical-grade oxide.
[3]Based on gross weight of purchased scrap consumed and estimated average nickel content.

TABLE 4
U.S. CONSUMPTION OF NICKEL, BY USE[1]

(Metric tons of contained nickel)

Use	2004								Grand total in 2003
	Metal	Ferronickel	Oxide and oxide sinter	Chemicals	Other forms	Total primary	Secondary (scrap)	Grand total	
Consumption, reported:									
Cast irons	52	W	--	--	7	59	252	311	591 r
Chemicals and chemical uses	597	--	W	5,700	--	6,300	--	6,300	2,400 r
Electric, magnet, expansion alloys	192	--	--	--	--	192	W	192	134
Electroplating, sales to platers	11,900	--	--	26	--	11,900	--	11,900	11,400
Nickel-copper and copper-nickel alloys	2,410	--	W	--	17	2,430	3,490	5,920	5,200 r
Other nickel and nickel alloys	12,700	W	W	--	70	12,800	2,620	15,400	14,600
Steel:									
Stainless and heat resistant	30,400	12,700	119	W	206	43,500	72,700	116,000	114,000 r
Alloys, excludes stainless	3,180	W	--	--	W	3,180	592	3,770	3,730 r
Superalloys	14,300	--	W	W	597	14,900	153	15,100	13,400 r
Other[2]	3,130	67	103	130	116	3,550	3,520	7,060	5,680 r
Total	78,900	12,800	222	5,860	1,010	98,800	83,300	182,000	171,000 r
Consumption, apparent	XX	XX	XX	XX	XX	129,000	54,900	183,000	165,000 r

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes batteries, catalysts, ceramics, coinage, other alloys containing nickel, and data indicated by the symbol "W."

TABLE 5
NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM, DECEMBER 31[1]

(Metric tons of contained nickel)

Form	2003	2004
Primary:		
Metal	3,440 r	3,980
Ferronickel	708 r	764
Oxide and oxide sinter	57	60
Chemicals	446	570
Other	152	150
Total	4,800 r	5,530
Secondary, scrap	6,270 r	5,210
Grand total	11,100 r	10,700

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

TABLE 6
U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS[1, 2]

Class	2003		2004	
	Quantity (metric tons of contained nickel)	Value (thousands)	Quantity (metric tons of contained nickel)	Value (thousands)
Primary:				
Unwrought:				
Cathodes, pellets, briquets, shot	996	$8,540	972	$10,900
Ferronickel	181	2,520	68	466
Powder and flakes	1,100	18,300	2,130	34,800
Metallurgical-grade oxide	160	1,950	201	2,140
Chemicals:				
Catalysts	1,930	76,100	1,980	104,000
Salts[3]	1,970	24,800	2,650	34,500
Total	6,330	132,000	8,000	186,000

See footnotes at end of table.

TABLE 6—Continued
U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS[1, 2]

Class	2003 Quantity (metric tons of contained nickel)	2003 Value (thousands)	2004 Quantity (metric tons of contained nickel)	2004 Value (thousands)
Secondary:				
Stainless steel scrap	37,800	$382,000	35,900	$548,000
Waste and scrap	9,460	41,900	12,400	60,800
Total	47,300	424,000	48,300	609,000
Grand total	53,600	557,000	56,300	795,000
Wrought, not alloyed:				
Bars, rods, profiles, wire	1,690	17,400	302	3,880
Sheets, strip, foil	1,040	15,600	579	10,900
Tubes and pipes	168	1,410	234	1,590
Total	2,890	34,400	1,120	16,400
Alloyed, gross weight:				
Unwrought alloyed ingot	6,660	74,200	7,510	80,600
Bars, rods, profiles, wire	9,150	145,000	12,300	224,000
Sheets, strip, foil	4,620	67,700	4,720	92,900
Tubes and pipes	2,420	44,700	1,800	50,700
Other alloyed articles	3,050	95,200	3,440	118,000
Total	25,900	427,000	29,700	566,000

[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]The nickel contents are as follows: metallurgical-grade oxide, 77%; waste and scrap, 50%; and stainless steel scrap, 7.5%. The salts category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; and sulfates, 22%. Other salts and various catalysts are assumed to be 22% nickel.
[3]Excludes nickel carbonate (more information can be found in the Harmonized Tariff System Schedule B, export commodity code 2836.99.9050).

Source: U.S. Census Bureau.

TABLE 7
U.S. EXPORTS OF NICKEL PRODUCTS, BY COUNTRY[1]

(Metric tons of contained nickel)[2]

Country	2004 Cathodes, pellets, and briquets (unwrought)	2004 Powder and flakes	2004 Ferronickel	2004 Metallurgical-grade oxide[3]	2004 Waste and scrap	2004 Stainless steel scrap	2004 Chemicals	2004 Total	Total in 2003	Wrought nickel in 2004[4]
Australia	1	5	--	--	114	1	2	123	63	7
Belgium	--	59	--	5	47	56	89	256	285	2
Brazil	112	22	--	(5)	--	20	13	167	320	18
Canada	17	208	28	3	9,910	1,850	1,950	14,000	11,900	94
China	--	413	3	(5)	65	11,800	117	12,400	6,560	174
Colombia	52	9	--	17	(5)	4	41	123	40	47
Finland	--	17	--	--	243	5,400	(5)	5,660	5,920	(5)
France	(5)	66	--	(5)	32	50	22	170	102	8
Germany	(5)	125	(5)	117	203	314	89	848	373	45
India	--	38	--	--	20	1,840	48	1,940	1,070	5
Italy	--	41	--	(5)	--	11	33	85	510	14
Japan	14	126	(5)	17	353	434	152	1,100	1,460	67
Korea, Republic of	1	102	(5)	1	20	6,670	203	7,000	7,050	30
Mexico	761	82	--	3	(5)	238	157	1,240	869	335
Netherlands	--	113	20	--	46	1,000	80	1,260	1,340	25
South Africa	--	3	--	21	30	--	18	72	115	--
Spain	--	(5)	--	--	--	696	(5)	696	2,580	(5)
Sweden	--	75	--	--	250	3	23	351	416	1
Taiwan	7	42	--	(5)	24	3,240	91	3,400	9,730	9
United Kingdom	2	115	17	15	790	266	67	1,270	1,170	60
Other	6	472	--	2	271	1,940	1,430	4,120	1,770	174
Total	972	2,130	68	201	12,400	35,900	4,630	56,300	53,600	1,120

See footnotes at end of table.

TABLE 7—Continued
U.S. EXPORTS OF NICKEL PRODUCTS, BY COUNTRY[1]

-- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]The nickel contents are assumed to be as follows: metallurgical-grade oxide, 77%; waste and scrap, 50%; and stainless steel scrap, 7.5%. The chemicals category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; and sulfate, 22%. Other salts and various catalysts are assumed to be 22% nickel.
[3]Chemical-grade oxide is included in the "Chemicals" category.
[4]Excluded from "2004, total."

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS[1]

	2003		2004	
Class	Quantity (metric tons of contained nickel)[2]	Value (thousands)	Quantity (metric tons of contained nickel)[2]	Value (thousands)
Primary:				
Unwrought:				
Cathodes, pellets, briquets, shot	99,300	$863,000	107,000	$1,450,000
Ferronickel	13,100	109,000	13,900	168,000
Powder and flakes	9,130	91,900	9,220	140,000
Metallurgical-grade oxide	91	835	1,210	17,500
Chemicals:				
Catalysts	1,610	64,900	1,310	68,800
Salts[3]	2,190	23,100	3,130	45,700
Total	125,000	1,150,000	136,000	1,890,000
Secondary:				
Stainless steel scrap	6,690	70,200	11,000	160,000
Waste and scrap	4,790	37,600	7,850	89,700
Total	11,500	108,000	18,800	250,000
Grand total	137,000	1,260,000	155,000	2,140,000
Wrought, not alloyed:				
Bars, rods, profiles, wire	289	4,760	499	9,740
Sheets, strip, foil	183	5,840	260	9,220
Tubes and pipes	187	2,780	38	1,350
Total	659	13,400	797	20,300
Alloyed, gross weight:				
Unwrought alloyed ingot	1,910	17,200	3,000	37,400
Bars, rods, profiles, wire	8,280	97,100	8,860	137,000
Sheets, strip, foil	3,540	42,500	2,920	58,600
Tubes and pipes	2,770	45,600	3,060	52,100
Other alloyed articles	1,770	74,600	2,080	63,600
Total	18,300	277,000	19,900	349,000

[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]The nickel contents are as follows: metallurgical-grade oxide from Australia, 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; sulfates, 22%; and other salts which are assumed to be 22% nickel. The typical catalyst is assumed to have a nickel content of 22%. Waste and scrap is assumed to be 50% nickel; stainless steel scrap, 7.5% nickel.
[3]Excludes nickel carbonate (more information can be found at Harmonized Tariff Schedule of the United States subheading 2836.99.5000).

Source: U.S. Census Bureau.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY COUNTRY[1]

(Metric tons of contained nickel)[2]

	2004									
Country	Cathodes, pellets, and briquets (unwrought)	Powder and flakes	Ferronickel	Metallurgical-grade oxide[3]	Waste and scrap	Stainless steel scrap	Chemicals	Total	Total in 2003	Wrought nickel in 2004[4]
Australia	10,800	500	--	19	90	--	5	11,400	12,000	--
Austria	--	(5)	--	--	5	--	--	5	(5)	208
Belgium	22	106	--	--	14	10	206	358	296	--
Brazil	1,920	--	--	--	78	90	--	2,080	1,210	--
Canada	54,500	4,730	--	1,190	1,810	7,330	17	69,600	44,900	2
China	--	--	--	--	22	5	50	77	94	25
Colombia	--	--	3,220	--	2	52	--	3,280	2,890	--
Dominican Republic	--	--	8,690	--	--	21	--	8,710	8,020	--
Finland	4,030	783	--	--	--	8	1,660	6,490	7,620	--
France	1,030	12	--	--	1,090	--	290	2,420	3,000	80
Germany	21	123	--	--	1,390	1	506	2,040	1,100	309
Japan	--	68	--	(5)	171	3	612	854	614	125
Mexico	(5)	--	--	--	169	1,970	61	2,200	2,290	--
Netherlands[6]	40	(5)	1	--	28	256	589	914	491	3
New Caledonia	--	--	1,360	--	--	--	--	1,360	1,670	--
Norway	14,800	--	--	--	22	--	--	14,800	17,300	--
Russia	18,000	1,380	654	--	--	--	--	20,100	27,800	--
South Africa	220	597	--	--	--	--	--	817	344	--
United Kingdom	686	869	--	--	2,000	1	114	3,670	2,950	9
Venezuela	--	--	--	--	76	367	--	443	83	--
Zimbabwe	941	--	--	--	--	--	--	941	716	--
Other	42	49	--	--	891	863	326	2,170	1,450 r	36
Total	107,000	9,220	13,900	1,210	7,850	11,000	4,440	155,000	137,000	797

rRevised. -- Zero.

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

[2]The nickel contents are assumed to be as follows: metallurgical-grade oxide from Australia, 90%; elsewhere, 77%. The chemicals category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; sulfates, 22%. Other salts and various catalysts are assumed to be 22% nickel. Waste and scrap is assumed to be 50% nickel, and stainless steel scrap, 7.5% nickel.

[3]Primarily oxide, rondelles, and sinter.

[4]Excluded from"2004, total."

[5]Less than ½ unit.

[6]The different nickel products (cathode, powder, etc.) are apparently materials that have transited through bonded warehouses in the Netherlands, including warehouses overseen by the London Metal Exchange.

Source: U.S. Census Bureau.

TABLE 10
NICKEL: WORLD MINE PRODUCTION, BY COUNTRY[1, 2]

(Metric tons of nickel content)

Country	2000	2001	2002	2003	2004
Australia, content of concentrate	166,500	205,000	207,800	210,000	178,100
Botswana, content of ore milled	38,420	26,714	28,600	32,740	32,980
Brazil, content of ore	45,317	45,456 r	44,928 r	45,160 r	45,200 e
Burma, content of ore[e]	40 [3]	40	30	30	30
Canada, content of concentrate	190,793	194,058	189,297	163,244 r	186,546
China[e]	50,300	51,500	53,700	61,000 r	64,000
Colombia, content of laterite ore	58,927	52,962	58,196	70,844	75,032
Cuba, content of oxide, oxide sinter, oxide powder, sulfide, ammoniacal liquor[4]	68,064	72,585	71,342	74,018	72,421
Dominican Republic, content of laterite ore	39,943	39,120	38,859	45,400 e	47,000 e
Finland, content of concentrate	3,347	2,200	2,500	2,700	2,800
Greece, content of laterite ore	19,535	20,830	22,670	21,410	21,700
Indonesia, content of laterite ore	98,200	102,000	123,000	143,000	133,000
Kazakhstan, content of laterite ore[e]	3,200 r	-- r	-- r	-- r	--
Macedonia, content of ferronickel produced	--	2,970 e	5,149	5,555	5,500
Morocco, content of nickel sulfate	84	151	109	126	126 e
New Caledonia, content of ore	126,041 r	117,734 r	99,841 r	112,013 r	118,279 p
Norway, content of concentrate[5]	2,538	2,529	2,052 r	169 r	181
Philippines, content of ore	17,388	27,359	26,532	19,537 r	16,973 p
Russia, content of ore[e]	315,000	320,000 r	305,000 r	310,000 r	315,000
South Africa, content of concentrate	36,616	36,443	38,546	40,842	39,850
Spain, content of concentrate	--	--	--	--	(6)
Turkey, content of laterite ore	--	--	--	640	-- [7]
Ukraine, content of laterite ore[e]	--	1,500	2,000	2,000	2,000
Venezuela, content of laterite ore	2,540	13,600	18,600	20,700	20,468
Zimbabwe, content of concentrate	8,160	10,120	8,092	9,517	9,520
Grand total	1,290,000	1,340,000 r	1,350,000	1,390,000 r	1,390,000
Of which:					
Content of concentrate	408,000	450,000	448,000	426,000	417,000
Content of ore and ore milled	542,000	537,000 r	505,000 r	519,000 r	528,000
Content of laterite ore	222,000 r	230,000 r	263,000 r	304,000 r	299,000
Content of ferronickel produced	--	2,970	5,150	5,560	5,500
Content of nickel sulfate	84	151	109	126	126
Content, unspecified and/or undifferentiated	118,000	124,000	125,000	135,000 r	136,000

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

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

[2]Insofar as possible, this table represents recoverable mine production of nickel. Where actual mine output is not available, data related to a more highly processed form have been used to provide an indication of the magnitude of mine output and this is noted parenthetically. North Korea may have an active nickel mine, but information is inadequate to make reliable estimates of output. Table includes data available through July 22, 2005.

[3]Reported figure.

[4]The Government of Cuba reports plant production on a contained nickel plus cobalt basis. The tonnages shown in this table for Cuba have been adjusted downward to correct for the cobalt. The cobalt content was determined to be 1.16% for granular and powdered oxide, 1.21% for oxide sinter, 7.56% for sulfide precipitate, and 33% for leach ammoniacal precipitate.

[5]A/S Nikkel Og Olivin halted mining operations in October 2002. Outokumpu Oyj sold its 70% interest in the Norwegian mining company to Boliden AB on December 30, 2003.

[6]The Aguablanca operation of Rio Narcea Gold Mines, Ltd. was commissioned in December 2004.

[7]European Nickel PLC began large scale heap leaching trials at its Caldag laterite operation in October 2004.

TABLE 11
NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT[1, 2]

(Metric tons of nickel content)

Country and product[3]	2000	2001	2002	2003	2004
Australia:					
Metal	98,700	116,900	120,800	115,800	111,000 p
Unspecified[4]	13,500	11,200	11,400	13,600 r	11,000 p
Total	112,200	128,100	132,200	129,400 r	122,000 p
Austria, ferronickel[e]	1,700	1,600	1,500	1,500	1,500
Brazil:[5]					
Ferronickel	6,347	5,768	6,011	6,409 r	6,400 e
Metal	16,906	17,663	17,676	18,155 r	18,200 e
Total	23,253	23,431	23,687	24,564 r	24,600 e
Canada, unspecified[6]	134,225	140,591	144,476	124,418	151,518
China, metal[e]	50,900	49,700 r	52,400	64,700	72,000
Colombia, ferronickel	27,730	38,438	43,987	47,868	49,200 p
Cuba, oxide sinter and oxides[7]	39,516	40,701	38,738	42,282	40,306
Dominican Republic, ferronickel	27,829	21,661	23,303	27,227	29,477
Finland:					
Metal	50,087	51,275	49,151 r	52,500 r	50,400
Chemicals	3,711	3,700	3,600	3,600	3,500
Total	53,798	54,975	52,751 r	56,100 r	53,900
France:					
Metal	10,100	11,033	9,444 r	9,138	10,103
Chemicals	2,176	2,000	2,000 e	2,000 e	2,000 e
Total[8]	12,276	13,033	11,444 r	11,138	12,103
Greece, ferronickel	17,126	16,870	19,229 r	18,000	18,115
Indonesia, ferronickel	10,111	10,302	8,804	8,933	7,945
Japan:					
Ferronickel	74,753	68,113	74,418	75,399 r	74,261
Metal	36,230	32,526	32,297	34,991	32,768
Oxide sinter	47,020	50,771	48,950	50,800 r	60,000
Chemicals	2,721	2,394	1,820	2,084	2,082
Total	160,724	153,804	157,485	163,274 r	169,111
Korea, Republic of, metal	(9)	(9)	(9)	(9)	(9)
Macedonia, ferronickel	--	2,970 e	5,149	5,555	5,500
Morocco, chemicals	84	151	109	126	126 e
New Caledonia, ferronickel	43,914	45,912	48,650	50,666	43,016
Norway, metal	58,679	68,221	68,530	77,183	71,410 p
Poland, chemicals[10]	732	704	744	785 r	820
Russia:[e]					
Ferronickel	7,000	8,000	12,000 r	13,500 r	14,000
Metal	225,000	230,000	219,000	239,000	243,000
Oxide sinter	14,000	12,000	6,000 r	5,000 r	5,000
Chemicals	2,000	2,000	2,000	2,500	3,000
Total	248,000	252,000	239,000 r	260,000 r	265,000
South Africa:					
Metal	30,900	30,500	31,646	25,500 e	32,700 e
Chemicals[11]	5,716	5,943	6,900	15,342	7,170 e
Total	36,616	36,443	38,546	40,842	39,900 e
Taiwan, metal	(9)	(9)	(9)	(9)	(9)
Ukraine, ferronickel[e, 12]	650	2,500	6,000	10,000	15,000
United Kingdom, metal	37,976	33,817	33,790	26,788 r	38,606
Venezuela, ferronickel	40	9,700	15,500	17,200	17,400 e
Zimbabwe, metal:					
Refined from domestic materials[13]	6,678	7,440	8,092	9,517	9,520
Toll refined from imported materials[14]	12,931	12,084	10,812	3,140	2,500 e
Total	19,609	19,524	18,904	12,657	12,000 e

See footnotes at end of table.

TABLE 11—Continued
NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT[1, 2]

(Metric tons of nickel content)

Country and product[3]	2000	2001	2002	2003	2004
Grand total	1,120,000	1,170,000 r	1,180,000 r	1,220,000 r	1,260,000
Of which:					
Ferronickel	217,000	232,000	265,000 r	282,000 r	282,000
Metal	635,000	661,000	654,000 r	676,000 r	692,000
Oxide sinter	101,000	103,000	93,700 r	98,100 r	105,000
Chemicals	17,100	16,900	17,200	26,400	18,700
Unspecified	148,000	152,000	156,000	138,000 r	163,000

eEstimated. pPreliminary. rRevised. -- Zero.

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

[2]Table includes data available through July 22, 2005.

[3]In addition to the countries listed, North Korea is believed to have produced metallic nickel and/or ferronickel, but information is inadequate to make reliable estimates of output levels. Several countries produce nickel-containing matte, but output of nickel in such materials has been excluded from this table to avoid double counting. Countries producing matte for export are listed in table 12.

[4]Class II products with a nickel content of less than 99%. Includes oxides and oxide sinter. Excludes intermediate nickel-cobalt sulfide matte, regulus, and speiss for further refining.

[5]Brazil produced nickel carbonate (an intermediate product), in metric tons: 2000—17,223; 2001—17,063; 2002—18,100; 2003—18,406 (revised); and 2004—18,400 (estimated).

[6]Nickel contained in products of smelters and refineries in forms, which are ready for use by consumers. Figures include the nickel content of nickel oxide sinter exported to the Republic of Korea and Taiwan. More information can be found in footnote 9.

[7]Cuba also produces nickel sulfide, but because it is used as feed material elsewhere, it is not included to avoid double counting. Combined output of processed sulfide and ammoniacal liquor precipitate was, as follows, in metric tons of contained nickel: 2000—28,548; 2001—31,884; 2002—28,548; 2003—31,736; and 2004—32,115. More information can be found in table 12.

[8]Reported by Eramet for Sandouville. Excludes secondary production from spent rechargeable batteries.

[9]Nickel metal production for the Republic of Korea and Taiwan are not included because the production is derived wholly from imported metallurgical-grade oxides and to include them would result in double counting. Metal estimates are as follows, in metric tons: Republic of Korea: 2000—29,890; 2001—26,429; 2002—30,337; 2003—32,200 (revised); and 2004—28,000 (preliminary). Taiwan: 2000—10,000; 2001—11,500; and 2002-04—11,000.

[10]Nickel content of nickel sulfate (NiSO4~6H2O). Most of the nickel sulfate was a byproduct of the concentrating, smelting, and refining of domestically mined copper ores. Some production, however, may have been derived from imported nickeliferous raw materials that were blended with the domestic copper concentrates.

[11]Includes nickel sulfate plus exported metal in concentrate.

[12]May include nickel in remelt alloys derived from scrap.

[13]Data represent production from domestic nickel ore.

[14]Previously published as "Other, metal." Data represent production from matte imported from Botswana as well as nickel sulfate imported from South Africa.

TABLE 12
NICKEL: WORLD PRODUCTION OF INTERMEDIATE PRODUCTS FOR EXPORT, BY COUNTRY[1, 2]

(Metric tons of nickel content)

Country	2000	2001	2002	2003	2004
Matte:					
Australia[3]	41,771	34,978	25,762	38,216	39,000 e
Botswana	24,218	22,454	23,896	27,400	22,292
Brazil[4]	8,475	10,183 r	6,289 r	5,962 r	6,000 e
Canada[e, 5]	36,000	48,000	50,000	45,000	45,000
China, exports[e, 6]	430	--	--	4,530	20
Indonesia[7]	59,200	62,600	59,500	70,200	68,576
New Caledonia	13,549	13,061	11,217	10,857	11,900 e
Russia[8]	515 r	-- r	7,783 r	3,866 r	599
Total	184,000	191,000	184,000 r	206,000 r	193,000
Other, Cuba:[9]					
Sulfide precipitate	27,288	29,914	30,858	29,620	30,999
Ammoniacal liquor precipitate	1,260	1,970	1,746	2,116	2,121
Total	28,548	31,884	32,604	31,736	33,120

See footnotes at end of table.

TABLE 12—Continued
NICKEL: WORLD PRODUCTION OF INTERMEDIATE PRODUCTS FOR EXPORT, BY COUNTRY[1, 2]

[e]Estimated. [r]Revised. -- Zero.
[1]Table includes data available through July 22, 2005. Data represent nickel content of matte and other intermediate materials produced for export.
[2]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
[3]Total matte production on a contained nickel basis, in metric tons, was as follows: 2000—103,019; 2001—96,550; 2002—91,574; 2003—107,000; and 2004—108,000 (estimated). Figures exclude toll-refined material.
[4]Represents the output of the Fortaleza smelter. All of the Fortaleza matte is being shipped to Finland for further processing.
[5]Estimated nickel content of reported exports. Matte from the Falconbridge smelter of Falconbridge Limited typically assays 55% nickel.
[6]Chinese exports were estimated to have a nickel content of 63%. Total matte production on a contained nickel basis, in metric tons, was estimated as follows: 2000—57,000; 2001—59,000; 2002—59,200; 2003—69,300 (revised); and 2004—70,000.
[7]Represents the nickel output of the Soroako smelter. The Soroako matte, which also contains cobalt, is being shipped to Japan for further processing.
[8]Russian figures reported primarily for exports to China from 2002 to 2004. Source: United Nations Statistics Division.
[9]Corrected for coproduct cobalt.

TABLE 13
NICKEL: NEW LATERITE PROJECTS SCHEDULED FOR COMPLETION, BY YEAR, BEFORE 2020

(Metric tons unless otherwise specified)

Projected year of first production	Country and state/province	Project and company	Resource grade (% nickel)	Estimated resources (thousands)[1]	Annual production capacity (of contained nickel)	Nickel product
2005	Philippines (Mindanao)	Adlay-Cagdianao-Tandawa BHP Billiton Plc and Case Mining and Development Corp.	1.61	6,000	5,000	Ore.
2005	Philippines (Palawan)	Rio Tuba Coral Bay Nickel Corp. (Sumitomo consortium)	1.26	16,000	10,000	Ni-Co sulfide.
2007	Australia (Western Australia)	Ravensthorpe BHP Billiton Plc	0.65	263,000	45,000	Ni-Co hydroxide.
2007	Brazil (Goias)	Barro Alto Anglo American plc	1.84 1.20	30,000 90,000	60,000	Ferronickel.
2007	New Caledonia (Southern)	Goro Inco Limited, Bureau de Recherches Geologiques et Minieres, and Sumitomo consortium	1.57	200,000	60,000	Ni oxide.
2007	Turkey (Manisa)	Caldag European Nickel PLC and BHP Billiton Plc	1.39 1.12	3,500 34,000	21,000	Leachate precipitate.
2008	Australia (Western Australia)	Young Jervois Resources Ltd.	1.00 0.59	44,000 152,000	4,500	Leachate precipitate, initially.
2008	Brazil (Para)	Vermelho Companhia Vale do Rio Doce	0.80	290,000	46,000	Metal or oxide.
2008	Do. Do.	Onca-Puma Canico Resource Corp.	1.86 1.25	78,000 91,000	25,000	Ferronickel.
2009	Cuba (Holguin)	Pinares de Mayari West Government of Cuba	1.10	400,000	40,000	Metal, oxide, or ferronickel.
2009	Kazakhstan (Kostanai Oblast)	Shevchenko Oriel Resources plc	1.02 0.70	34,000 68,000	30,000	Ferronickel.
2009	Madagascar	Ambatovy Dynatec Corp. and Sumitomo Corp.	1.10	190,000	60,000	Metal.
2009	New Caledonia (Northern)	Koniambo Falconbridge Ltd. and Soc. Miniere du Sud Pacifique S.A.	2.13 2.20 1.60	140,000 160,000 130,000	60,000	Ferronickel.
2010	Do. Do.	Nakety-Bogota Argosy Minerals, Inc. and Soc. des Mines de la Tontouta	1.47 1.50	88,000 140,000	52,000	Ni-Co intermediate.
2011	Australia (Western Australia)	Mount Margaret Minara Resources Ltd. (formerly Anaconda Nickel Ltd.)	0.78	170,000	45,000	Ni-Co hydroxide.
2011	Cuba (Camaguey)	San Felipe Government of Cuba	1.30	250,000	45,000	Metal or oxide.
2011	Indonesia (Halmahera Island)	Weda Bay Weda Bay Minerals, Inc. and PT Aneka Tambang	1.37 1.35	159,000 23,000	48,000	Ni-Co sulfide.

See footnotes at end of table.

TABLE 13—Continued
NICKEL: NEW LATERITE PROJECTS SCHEDULED FOR COMPLETION, BY YEAR, BEFORE 2020

(Metric tons unless otherwise specified)

Projected year of first production	Country and state/province	Project and company	Resource grade (% nickel)	Estimated resources (thousands)[1]	Annual production capacity (of contained nickel)	Nickel product
2012	Australia (Queensland)	Marlborough/Gladstone Gladstone Pacific Nickel Ltd.	1.02	210,000[2]	30,000	Metal.
2012	Guatemala	Sechol	1.40	37,000[2]	NA	Ni-Co intermediate.
		Jaguar Nickel Inc.	1.50	100,000		
2013	Papua New Guinea (Madang)	Ramu China Metallurgical Construction (Group) Corp., Highlands Pacific Ltd., and Mineral Resources Development Co.	0.91 1.01	76,000 67,000	33,000	Metal.
2013	Philippines (Mindoro Island)	Sablayan Crew Development Corp.	0.94	72,000	40,000	Do.
2014	Australia (New South Wales)	Syerston Ivanhoe Nickel and Platinum Ltd.	0.69	96,000	18,000	Ni-Co sulfide concentrate.
2014	Australia (Western Australia)	Kalgoorlie and North Kalgoorlie—Ghost Rocks, Goongarrie, and Kalpini Heron Resources Ltd. and Inco Limited	1.20 0.83	100,000 225,000	50,000	Ni-Co hydroxide.
2015	Indonesia (Maluku)	Gag Island BHP Billiton Plc and PT Aneka Tambang	1.35	240,000	30,000	Intermediate, metal, or ferronickel.
2015	New Caledonia (Southern)	Prony Inco Limited, Bureau de Recherches Geologiques et Minieres, and Sumitomo consortium	1.50	NA[2]	NA[2]	Ni oxide.
2015	Papua New Guinea (Oro)	WoWo Gap Resource Mining Corp. Ltd.	1.09 1.44 1.02	31,000 18,000 18,000	45,000	Metal.
2018	Cote d'Ivoire	Biankouma, Touba, and Sipilou Falconbridge Ltd. and Soc. d'Etat pour le Developpement Minier	1.57 1.40	120,000 140,000	45,000	Ni-Co intermediate or ferronickel.
2019	Indonesia (Sulawesi)	La Sampala Rio Tinto plc	1.50 1.30	195,000 185,000	NA	NA

NA Not available.

[1]Gross weight, dry. "Estimated resources" are rounded to no more than two significant digits. When two or more data sets are listed, the first resource data represent measured resources; the second, indicated resources; and the third, inferred resources.

[2]New resource estimate in progress.

Sources: Company annual reports, presentations, and press releases; CRU International, Ltd.

TABLE 14
NICKEL: NEW SULFIDE PROJECTS SCHEDULED FOR COMPLETION, BY YEAR, BEFORE 2020

(Metric tons unless otherwise specified)

Projected year of first production	Country and state/province	Project and company	Resource grade (% nickel)	Estimated resources (thousands)[1]	Annual production capacity (of contained nickel)	Nickel product
2005	Canada	Voisey's Bay	2.88	31,000	50,000	Concentrates, initially.
	(Labrador)	Inco Limited	1.29	97,000		
			0.98	14,000		
2006	Australia	Forrestania-Flying Fox, New Morning and	5.60	430	7,000	Concentrates.
	(Western Australia)	Diggers South				
		Western Areas NL	1.67	1,700		
2006	Do.	Lanfranchi	2.02	3,650	10,000	Ore.
	Do.	Sally Malay Mining Ltd. and Donegal				
		Resources Ltd.				
2007	Do.	Honeymoon Well	0.82	140,000	10,000	Concentrates, initially.
	Do.	LionOre Australia Ltd.				
2007	Do.	Sherlock Bay	0.49	33,000	8,500	Precipitated leachate.
	Do.	Sherlock Bay Nickel Corp. Ltd.				
2007	Canada	Norman-North, Whistle Pit, and '2000'	0.95	(2)	NA	Ore.
	(Ontario)	FNX Mining, Inc. and Dynatec Corporation				
2008	United States	NorthMet	0.11	810,000	7,100	Byproduct concentrate
	(Minnesota)	PolyMet Mining Corp.				of Ni-Co hydroxide.
2009	Australia	Cosmos South, Alec Mairs, Anomaly 1	0.74	36,000	10,000	Concentrates.
	(Western Australia)	Jubilee Mines NL				
2009	Canada	Nickel Rim South	1.60	14,000	10,000	Do.
	(Ontario)	Falconbridge Limited				
2009	Tanzania	Kabanga	2.60	26,000	30,000	Do.
	(Kagera region)	Barrick Gold Corp. and Falconbridge Limited				
2009	United States	Eagle	3.80	3,600	NA	Ore.
	(Michigan)	Kennecott Minerals Company	2.20	500		
2010	Australia	Yakabindie	0.58	290,000	40,000	Do.
	(Western Australia)	BHP Billiton Plc				
2010	United States	Mesaba	0.12	300,000	20,000	Byproduct concentrate
	(Minnesota)	Teck Cominco American, Inc.				of Ni-Co sulfide or hydroxide.
2011	Australia	Waterloo and Amorac	(2)	(2)	NA	Concentrates.
	(Western Australia)	LionOre Australia Ltd.				
2011	Canada	Maskwa	0.74	6,000	3,800	Do.
	(Manitoba)	Mustang Minerals Corp.	0.75	550		

NA Not available.

[1]Gross weight, dry. "Estimated resources" are rounded to no more than two significant digits. When two or more data sets are listed, the first resource data represent measured resources; the second, indicated resources; and the third, inferred resources.

[2]Resource estimate in progress.

Sources: Canadian Minerals Yearbook 2003; company annual reports, presentations, and press releases; and CRU International, Ltd.