# NICKEL

By Peter H. Kuck

Throughout 1997, nickel producers struggled to cut costs in the face of weakening prices for the metal. The spot price of nickel has been gradually declining since the spring of 1996 despite firm demand for the metal in North America. The monthly average cash price for 99.8% pure metal on the London Metal Exchange (LME) reached a 2-year low of $6,581 per metric ton in December 1996, climbed briefly to $7,896 during the first quarter of 1997, and then entered a period of deterioration lasting more than 15 months. By January 1998, the monthly cash price had dropped to a 4-year low of $5,492 per ton and was still slipping. Several analysts attributed the extended price decline to concerns about anticipated new mine production capacity (Mining Journal, 1998). More than 160,000 tons of capacity (on a contained nickel basis) are scheduled to come on-stream between mid-1998 and 2002. Most of these new mines would be in Australia (van Os, 1998). Some of the Australian mines would refine the nickel on-site, while others would ship concentrates or matte to Outokumpu Oyj's recently expanded refinery in Finland. Since 1992, global nickel supplies have more than kept pace with growing demand for the metal in the Western World and a short-term oversupply situation beginning in 2001 cannot be ruled out. Exports of primary nickel from Russia have remained firm, while consumption inside the country has plummeted. The recent financial crisis in Asia has created problems for several major stainless steel producers and psychologically discouraged investment in nickel by commodity funds and banking houses (Mining Journal, 1998).

The deterioration of prices coincided with the launching of several new nickel mines in Australia, the modernization of beneficiation facilities in Cuba, and extensive expansions of downstream production operations in Indonesia, Norway, and the United Kingdom. New mining projects were also at various stages of development in Brazil, New Caledonia, Ontario, Quebec, and Venezuela.

Development of the world class Voisey's Bay nickel-copper-cobalt deposit in Labrador was still at a very early stage and was proceeding slower than anticipated because of the complex environmental review and approval process. Weak nickel and copper prices destroyed much of the incentive for Inco Limited and Canadian authorities to accelerate their negotiations and reach an early agreement. Inco gained control of the Voisey's Bay deposit in August 1996 by acquiring its owner, Diamond Fields Resources Inc. Inco paid the shareholders of Diamond Fields $3.1 billion in cash and stock to surrender their holdings. The Voisey's Bay complex is the first major mining and milling project to be subjected to a full review under Canada's new Environmental Assessment Act. Inco submitted its environmental impact statement to Canadian federal and provincial authorities in December 1997 and was still negotiating impact and benefit agreements with the local Labrador Innu and Innuit communities at yearend. The settlement was linked to the outcome of independent land claim negotiations underway between the Federal and Provincial Governments and the two First Peoples Nations. By yearend 1997, exploration drilling at Voisey's Bay had delineated 116 million tons of sulfide ore resources. Five ore bodies have been identified to date, with average grades ranging from 1.36% to 2.83% nickel (Ni), 0.65% to 1.68% copper (Cu), and 0.09% to 0.12% cobalt (Co) (McCutcheon, 1998). The Voisey's Bay project, the modernization of operations at Sudbury, Ontario, and the new Raglan Mine in northern Quebec should solidify Canada's position as a leading supplier of nickel far into the 21st century.

Russia continued to be the world's largest producer of nickel, with the bulk of its output coming from mines operated by RAO Norilsk Nickel in the Arctic. In 1997, Norilsk Nickel accounted for 94% of total Russian production. The newly privatized company continued to restructure all of its mining and processing operations and produced 23% more nickel than in 1996. Norilsk Nickel has a large nickel-copper smelting complex on the Taimyr Peninsula in Siberia and two more on the Kola Peninsula bordering Finland. Outokumpu Oyj of Finland was helping Norilsk Nickel evaluate, upgrade, and modernize all three complexes. Outokumpu Oyj pioneered flash smelting and is 1 of the top 10 nickel producers in the world. Modernization of the three complexes—at Norilsk, Monchegorsk, and Pechenga—has been hampered by low nickel prices and the enormous amounts of capital required to make the operations environmentally acceptable and economically competitive. Officials of Norilsk Nickel and the Russian Federation have been negotiating since 1993 with potential financial backers from Scandinavia for a significant portion of the $1 billion needed to modernize the Pechenga smelter. New pollution control equipment was needed to sharply reduce sulfur dioxide ($SO_2$) emissions from Pechenga and help improve air quality across much of Lappland (Blatov, I.A., and others, 1996).

In September, QNI Limited of Australia agreed to purchase the nickel division of Billiton Plc (formerly owned by Gencor Limited of South Africa). QNI funded the purchase by issuing a large block of new shares to Billiton Plc, which gave Billiton a controlling interest of 52.5% in the enlarged QNI. The merger of QNI and Billiton Nickel created the fifth largest nickel producer in the world, with a market capitalization of about A$2 billion (QNI Limited and Billiton Plc, 1997).

Several key mining projects have been proposed for Cuba. Exploration was underway in Camaguey and Holguín Provinces. Metals Enterprise, a 50-50 venture of Sherritt International Corporation and the Government of Cuba, continued to modernize the laterite mining and beneficiation complex at Moa in spite of the U.S. embargo. The bulk of the sulfide precipitate was being shipped to the joint venture's refining complex at Fort

Saskatchewan, Alberta. World War II-vintage operations at Nicaro also were being rehabilitated.

Stainless steel currently accounts for about 65% of primary nickel demand in the entire world (Upton, 1998). Another 5% is consumed in the production of alloy steels. Over the last 20 years, stainless steel production in the Western World has been growing at an average rate of 4.5%, down somewhat from the long-term trend of 6%.

In 1997, apparent U.S. demand for primary nickel was 154,000 tons, 5% more than that of 1996. About 40% of the nickel was used to make austenitic stainless steel. U.S. demand for stainless steel was up 6%, with about 25% of the demand being met by imports. U.S. stainless production increased 12% to a record high 2.16 million tons (American Iron and Steel Institute, 1998a). On a per capita basis, the United States consumes significantly less stainless steel than Germany, Italy, Japan, the Republic of Korea, and Taiwan (Inco Limited, 1997c). While the European Union (EU) reported an increase of 12% in stainless steel production, it had an output of 6.89 million tons—more than three times that of the United States. Japanese stainless steel production was up only slightly (International Nickel Study Group, 1998b). Japan's output was 3.26 million tons—1.5 times that of the United States. For the first time, the combined stainless steel production of the Republic of Korea and Taiwan equaled that of the United States. Since 1995, Korea's Pohang Iron and Steel Company (POSCO) and Taiwan's Yeih United Steel Co. Ltd. have added significant stainless steel production capacity. Stainless steel production remained depressed in Russia because of that country's continuing economic restructuring.

Demand for primary nickel by battery manufacturers continued to grow, although the tonnages involved were an order of magnitude smaller than those for stainless steel. Rechargeable nickel-cadmium and nickel-metal hydride batteries were in strong competition with one another for hand-held power tools, cellular telephones, laptop computers, and camcorders. The bulk of the nickel-based batteries imported into the United States were made in Japan, Mexico, China, Taiwan, or Malaysia (in descending order of market share). Industry analysts estimate that, in 1997, Japan manufactured 77% of the rechargeable batteries consumed worldwide. About 94% of the nickel-metal hydride batteries was produced by Japanese companies or Japanese-owned companies (Koyama, 1998).

Electric vehicles (EV's) were being commercially manufactured in the EU, Japan, and the United States. However, production and sales were limited. The servicing infrastructure and the network of charging stations needed to support a large number of EV's were still in a state of infancy. In the United States, few charging stations were available to the public outside of Arizona, California, and Washington State. The first vehicles mass produced by PSA Peugeot-Citroën and Renault of France were powered by nickel-cadmium batteries. The batteries were being made by SAFT S.A. at its new plant in Bordeaux. The two French automotive companies were in the process of switching to SAFT's new nickel-metal hydride batteries and were also testing lithium-ion battery prototypes. Honda Motor Co. Ltd. of Japan was using nickel-metal hydride batteries in its new EV Plus, a two-door sedan. In May, Honda began leasing the EV Plus to California fleet owners. The first models of the EV-1 being sold by General Motors Corp. in Arizona and Southern California had lead-acid batteries, limiting its range. The Detroit auto manufacturer was planning to introduce a nickel-metal hydride-powered version in the fall of 1998.

In December 1997, Toyota Motor Corporation began selling its new hybrid-powered Prius sedan in Japan and was planning to introduce the vehicle in the United States in late 2000. The vehicle's hybrid power system has both a gasoline engine and an electric motor. The Prius has almost twice the fuel efficiency of an equivalent conventional sedan.

## Legislation and Government Programs

***Cuban Embargo***.—Efforts to normalize relations between Cuba and the United States continued to run into roadblocks (Gershman, 1998; Rohter, 1999). Mediation attempts by multinational institutions and even the Holy See made little headway (Fineman, 1998; Fineman and Boudreaux, 1998). New legal restrictions were imposed, and the routine exchange of nonsensitive information between Cuban nickel producers and the U.S. Government became increasingly difficult.

Cuban nickel production is growing despite the U.S. embargo. In 1995, the Cuban nickel industry launched a major rehabilitation program with the help of foreign investors. The introduction of state-of-the-art technology and improved management practices has led to a sharp rise in productivity. Cuba has the largest reserve base of nickel-bearing laterites in the world. Three mining and smelting complexes are currently producing nickel on the island. Nicaro and Punta Gorda produce nickel oxide by the ammonium-carbonate leach process and are operated by La Compania General de Niquel S.A. (General Nickel), a parastatal enterprise (Suttill, 1994). The third, Moa, produces a nickel-cobalt sulfide precipitate that is shipped to Canada for further processing. Moa is operated as a joint venture of Sherritt International Corporation and General Nickel. The Cuban Government and Sherritt are equal partners in the Moa venture. (*See Cuba section of this review.*)

All three nickel plants are in Holguín Province at the southeastern end of the island. Two of the three plants—Moa and Nicaro—were expropriated from U.S. owners in 1960. None of the nickel and cobalt production can be marketed in the United States because of the U.S. embargo against Cuba. Importation of Cuban nickel is prohibited under the Cuban Assets Control Regulations, 31 CFR, part 515. The U.S. Government also has bilateral agreements on this issue with several major nickel-consuming nations.

In March 1996, the President signed into law "The Cuban Liberty and Democratic Solidarity (LIBERTAD) Act." The LIBERTAD Act (Public Law 104-114) codified existing executive orders imposing an economic embargo on Cuba and has discouraged foreign investment in Cuba. The legislation is commonly referred to in the press as the Helms-Burton Law, after its Congressional authors. The law gave American citizens, who had property illegally expropriated by the Cuban Government, on or after January 1, 1959, the right to sue in U.S. courts any foreign company that makes use of the property. In addition, entry into the United States can be denied to foreign corporate officials and other principals found trafficking in expropriated

Cuban properties. The EU disapproved of the LIBERTAD Act and responded by taking the whole matter of the Cuban embargo to the newly formed World Trade Organization (WTO). Canada and Mexico supported the position taken by the EU.

One of the more controversial parts of the LIBERTAD Act has been Title III, which makes persons who knowingly traffic in properties expropriated by the Cuban Government subject to private civil damage suits in Federal district court. Title III was to have taken effect on August 1, 1996. However, the Act gave the President the authority to suspend Title III and the filing of claims for up to 6 months, and for additional 6-month periods, if suspension would help expedite a transition to democracy in Cuba (U.S. Department of Justice, 1996). On January 3, 1997, the President suspended Title III for the second time. In February, the EU requested that the World Trade Organization appoint a panel to judge the legality of the U.S. economic sanctions against Cuba. The United States did not accept WTO jurisdiction and argued that the LIBERTAD Act was not a trade dispute but a national security issue. In April, the EU and the United States reached an understanding that temporarily defused the dispute. The President agreed to try to persuade Congress to modify the Act in exchange for a 6-month suspension of the WTO complaint (Blustein and Lippman, 1997). On July 16, the President waived Title III for a third 6-month period (Lippman, 1997). Diplomatic resolution of the dispute was expected to take some time.

Senior officials of Sherritt International were some of the first individuals to be barred from the United States under Title IV of the new law. The law strengthened earlier actions taken by the Department of the Treasury. Several company officials who helped form the joint venture have been on the U.S. Government's List of Blocked Persons and Specially Designated Nationals since June 1995.

***Environmental Regulations***.—In May 1996, the President signed "The Mercury-Containing and Rechargeable Battery Management Act" (Public Law 104-142). The law was designed to make the reclamation of spent consumer batteries more economically feasible and to remove regulatory burdens from the battery recycling industry. The law covers a broad spectrum of household and industrial batteries, including those used in portable tools, office equipment, emergency power supplies, and EV's. A key part of the law refers specifically to spent nickel-cadmium batteries. Title I of the law established uniform national labeling requirements for nickel-cadmium, small sealed lead-acid, and certain other regulated batteries. Each battery or battery pack must bear a recycling symbol and a recycling phrase appropriate to its electrode chemistries. The labeling requirements are similar to ones already adopted by Japan. Domestic battery manufacturers and importers were to be in complete compliance with the labeling requirements by May 1998. Title I also provided for the streamlining of regulations governing battery collection and recycling.

The law also directed the U.S. Environmental Protection Agency (EPA) to work with battery manufacturers, manufacturers of consumer products, and retailers in disseminating proper handling and disposal information on batteries to the general public. The Portable Rechargeable Battery Association, a nonprofit trade association composed of more than 100 manufacturers, distributors, assemblers, users, and sellers of small rechargeable batteries, was in the process of setting up a nationwide collection and recycling system. The program was being administered by the Rechargeable Battery Recycling Corporation (RBRC). At the beginning of 1997, the RBRC still needed regulatory approval from 37 of the 50 States. The bulk of the spent nickel-cadmium and nickel-metal hydride batteries were being shipped to a pyrometallurgical reclamation facility at Ellwood City, PA. The facility is operated by the International Metals Reclamation Co. Inc., a subsidiary of Inco Limited.

Many metropolitan areas of the United States continued to struggle with air pollution problems and traffic congestion. The Federal Government, most of the 50 States, and many municipal authorities now have programs designed to reduce exhaust emissions from automobiles and other self-powered machinery propelled by internal combustion engines. On June 6, 1997, EPA established the regulatory framework for its National Low Emission Vehicle program. The voluntary program still must be approved by the Ozone Transport Commission and the auto manufacturers (U.S. Environmental Protection Agency, 1997). California, Massachusetts, New York, and several other States have or were negotiating agreements with the automotive industry to encourage the development and sale of electric vehicles. California, faced with severe air pollution problems in the Los Angeles Basin, was in the forefront. Beginning in model year 2003, 10% of all automobiles sold in California must be EV's or some other type of zero emission vehicle (ZEV). Seven leading automobile manufacturers have signed agreements with the California Air Resources Board (CARB) specifying EV sales targets and shipment deadlines (Evashenk, 1998). The auto manufacturers also have agreed to begin selling low-emission vehicles—the so-called 49-State car—in 2001.

Several auto manufacturers began limited production of EV's in 1997. Only four battery chemistries were being used in the initial production runs—lead-acid, nickel-cadmium, nickel-metal hydride, and lithium-ion. General Motors Corp. was using an advanced lead-acid battery pack in its EV-1, but was planning to introduce a nickel-metal hydride pack in late 1998. Honda and Toyota were using nickel-metal hydride packs in their EV's, but were initially restricting sales in the United States to fleet owners. Toyota's Prius, a hybrid vehicle which also uses a nickel-metal hydride battery, was not scheduled to be introduced into the United States until the latter half of 2000. At yearend 1997, about 1,100 "pure" electric vehicles were registered in California.

In December 1996, the President of the United States signed an Executive order designed to encourage the use of EV's and other alternative fueled vehicles (AFV's) in metropolitan areas of the country (Presidential Documents, 1996). Executive Order 13031 (Federal Alternative Fueled Vehicle Leadership) required each Federal Agency to immediately develop and implement plans for acquiring AFV's. In fiscal year (FY) 1998, 50% of the general-use vehicles acquired were to have been AFV's. This percentage was to increase to 75% in FY 1999 and remain at that level for subsequent years. Several Government agencies, faced with tight budgets, were stymied by the high prices of the first production EV's and their limited range. To meet their initial goals, some turned to low-emission AFV's that run on compressed or liquified natural gas. EV prices were expected to fall as production increases and a market for used EV's develops.

***New Coinage***.—The European Union and the United States are in the process of issuing new coinage. However, the two governments have taken different positions with respect to nickel. The EU is planning to limit nickel in its new coinage to minimize the potential risk of hypersensitive members of the public contracting nickel dermatitis. The U.S. Mint, on the other hand, favors the cupro-nickel cladding now in circulation and apparently has received few complaints about the cladding causing nickel dermatitis. Canada has had coins composed of 100% nickel in circulation since at least 1922. Today, the Canadian 10-cent piece and 25-cent piece are still composed of pure nickel. Both the Canadian and United States 5-cent coins are composed of 25% nickel and 75% copper.

On December 1, 1997, the President signed into law legislation authorizing the minting over the next decade of some 2 to 3 billion nickel-bearing commemorative quarters (25-cent coins) per year. The new law is entitled "The 50 States Commemorative Coin Program Act of 1997" (Public Law 105-124). The minting program will honor each of the 50 States of the Union.

The new coin would closely resemble the clad quarter dollar currently in circulation. The obverse (i.e., front) side of the coin would still bear the likeness of George Washington. However, the reverse side would bear an emblem of 1 of the 50 States. Minting would begin in 1999, with five States being honored each year. The redesigned quarters are to be issued in the order in which the States ratified the U.S. Constitution or were admitted into the Union. The program is expected to earn $3 billion to $5 billion for the Treasury, with the proceeds being used to reduce the national debt (Library of Congress, 1997, 50 States Commemorative Coin Program Act (previously Senate Bill 1228): Bill summary & status for the 105th Congress, 18 p., accessed December 12, 1997, at URL http://thomas.loc.gov/cgi-bin/).

The metal content, size, and shape of the coin will not change. The "Eagle" quarter now in circulation contains 8.33% nickel and 91.67% copper (Platt's Metals Week, 1997d). The coin has a core of pure copper and outer layers composed of a 25% nickel- 75% copper alloy. The coin has a diameter of 24.3 millimeters and weighs 5.67 grams. More than 930 tons of nickel and 10,400 tons of copper would be required annually to make the new coins.

The European Monetary Union is planning to have its new euro coinage in circulation by January 1, 2002. There are to be eight denominations—1, 2, 5, 10, 20, and 50 eurocent plus the 1 and 2 euro. After July 1, 2002, coins of the individual member States will no longer be legal tender. Environmental groups in Europe are concerned that long-term contact with coins made from nickel alloys could produce nickel dermatitis in some hypersensitive individuals. Because of these health considerations, the European Commission has proposed using a nickel-free alloy called "Nordic Gold" for the 10, 20, and 50 eurocent coins. The 1, 2, and 5 eurocent coins would be copper-covered steel and also nickel-free (Fortis Nederland, 1997). For technical reasons, the large 1 and 2 euro coins would contain limited amounts of nickel. Minting of the first euro coinage began in 1998. An estimated 70 billion coins are currently circulating in the 15 member States of the European Union. About 75% of the coins contain nickel. The changeover would cause this percentage to fall to 8%.

***Defense Stockpile Sales***.—The Defense Logistics Agency (DLA) continued to sell nickel from the National Defense Stockpile (NDS) and was rapidly reducing its holdings. The Government had 33,760 tons of nickel in inventory when the sales started on March 24, 1993. All 33,760 tons was some form of electrolytic metal except for 399 tons contained in 520 tons of oxide of Cuban origin. The ongoing sales are part of a much larger downsizing of the stockpile approved under the Defense Authorization Act of 1992 (Public Law 102-484). By the end of 1996, uncommitted stocks had shrunk to 10,257 tons—all of it metal. An additional 5,602 tons was awaiting pickup on December 31, 1996, for a total physical inventory of 15,859 tons. In 1997, DLA warehouses turned over 7,334 tons to purchasers, leaving uncommitted stocks of 3,227 tons on December 31. Total yearend stocks also included 4,885 tons of committed material, for a grand total of 8,112 tons. This total excludes 413 tons of material presently unavailable for sale. In 1997, nickel was being offered at monthly auctions and through privately negotiated long-term solicitations. At the currently authorized rate of sales, the remaining stocks of metal should be exhausted by late 1999.

## Production

In 1997, the United States had only one primary nickel producer—the Glenbrook Nickel Co. of Riddle, OR. Glenbrook operated at full design capacity for most of the year, producing 16,000 tons of nickel contained in ferronickel and breaking the previous record of 15,100 tons just set in 1996. The smelter is on the southern slope of Nickel Mountain in Douglas County and was built in 1954 to process garnierite-rich lateritic ores mined from an open pit on the mountain top. Since 1991, a large part of the ore fed to the smelter has come increasingly from the South Pacific Island of New Caledonia. The Oregon operation is a subsidiary of Cominco American Inc., which, in turn, is wholly owned by Cominco Ltd. of Vancouver, British Columbia.

All of the ferronickel produced by Glenbrook in 1997 was made from New Caledonian ore. The Nickel Mountain Mine was kept on standby the entire year because of low nickel prices. The nickel content of the New Caledonian ore is significantly higher than that from Nickel Mountain (2.3% vs. 1.25% nickel on a dry basis). At yearend, the Nickel Mountain Mine had only 230,000 tons of reserves remaining. However, additional resources of similar grade were available from other lateritic deposits in Douglas County and neighboring Josephine County.

In late 1997, Cominco took steps to permanently close the Oregon complex when the world price fell below $6,000 per ton ($2.72 per pound) (Cominco Ltd., 1998; Kelly, 1998). The Glenbrook workforce made significant improvements in productivity during the year, reducing production costs (Robinson, 1998). Unfortunately, the cost cutting could not keep up with the drop in the LME price. Cominco carried out an indepth feasibility study of the Glenbrook operation before deciding to close the facility. Complete modernization was one of the options considered in the study. Glenbrook's overall cost of producing ferronickel could conceivably be lowered to less than $2.00 per pound Ni, while increasing capacity by 50% if the existing ferronickel furnaces were replaced by carbothermic furnaces at an estimated cost of $100 million. Prospective buyers have been mulling this option, but were worried that the projected startup of the huge Voisey's Bay Mine in Labrador in 2002 or 2003 would make even an upgraded operation economically uncompetitive. Japanese producers of ferronickel were reportedly in a similar predicament. Glenbrook spent $1 million in 1997 carrying out pilot scale and demonstration tests of the new furnace technology.

Inmetco, a subsidiary of Inco Limited, continued to produce nickel-chromium-iron remelt alloy at its metals recovery facility in Ellwood City, PA. The facility was set up in 1978 to reclaim chromium and nickel from emission control dusts, swarf, grindings, and mill scale—all wastes generated by the stainless steel industry. Because of subsequent improvements to the facility, Inmetco can accept a broad spectrum of other recyclable nickel- and/or chromium-bearing wastes, including filter cakes, plating solutions and sludges, catalysts, refractory brick, and spent batteries (Barozzi, 1997). The company now accepts three types of spent nickel-based batteries—nickel-cadmium, nickel-metal hydride, and nickel-iron—but asks shippers to segregate the latter two from the nickel-cadmium batteries whenever feasible. In December 1995, Inmetco commissioned a state-of-the-art facility equipped with electric-powered distillation furnaces to make the processing of nickel-cadmium battery waste more economically feasible (Rundquist, 1997). The cadmium is fumed off in the distillation furnace and reclaimed as pure metal, leaving behind a nickel-iron residue. The nickel-iron residue is then shredded and added to the main feedstream of the plant.

The bulk of the feedstock for the Ellwood City plant is prepared by (1) blending a variety of liquid and solid wastes containing nickel, chromium, and iron, (2) adding waste carbon as a reductant, and then (3) pelletizing the wet mixture. The green pellets are partially reduced—together with the shredded battery scrap—in a rotary hearth furnace at 1,260º C. After 20 minutes, the hot material is transferred from the rotary hearth to a 6.3-megavolt-ampere submerged arc furnace where the material is smelted and reduction of the metal oxides is completed. In 1996, Inmetco produced about 21,400 tons of chromium-nickel-iron alloy from material that would otherwise be disposed of in landfills. The 21,400 tons of alloy contained 15,100 tons of iron, 3,400 tons of chromium, 2,600 tons of nickel, and 330 tons of molybdenum (The International Metals Reclamation Co., Inc., 1997).

Limited quantities of nickel were recovered at some copper and precious metals refineries and at a few plants that reclaim spent catalysts.

In 1996, the Stillwater Mining Company constructed a base metals refinery adjacent to its precious metals smelter at Columbus, MT. The new refinery has begun producing a byproduct copper-nickel-cobalt solution which is shipped by truck to Canada where the three metals are eventually recovered (Stillwater Mining Company, 1998b). The company has been mining palladium, platinum, rhodium, and gold since 1986 from the Stillwater Complex at Nye in Montana's Beartooth Mountains. The Stillwater Mine is one of the few significant sources of platinum-group metals (PGM) outside of Russia and South Africa. The ore is crushed, ground, and floated at the minesite to liberate the PGM-bearing sulfides from the rock matrix. From Nye, the sulfide concentrate is transported in trailers 74 kilometers (46 miles) to Columbus, where it is fed into a 1.5-megawatt electric furnace and made into matte. The furnace matte is remelted in one of two top-blown rotary converters to separate the bulk of the accompanying iron from the more valuable metals. The resulting iron-depleted converter matte is a mix of copper and nickel sulfides containing about 2% PGM by weight. The precious metals smelter was expanded in 1997 and can now process up to 32 tons per day of concentrate.

At the refinery, the converter matte is leached with sulfuric acid to dissolve the nickel, copper, cobalt, and any remaining iron. The undissolved residue, which contains 55% to 60% platinum plus palladium, is pressure leached in autoclaves and made into a filter cake that can be sold to precious metal refiners. At yearend, the Stillwater Mining Company was planning to build a copper-nickel recovery circuit at its Columbus complex (Stillwater Mining Company, 1998a). The copper-nickel recovery circuit would cost about $6 million.

**Consumption**

Demand for primary nickel in the Western World increased about 10% and was estimated to be about 933,000 tons—an alltime high (International Nickel Study Group, 1998b). The tonnage was 4% more than the previous record of 894,000 tons set in 1995 (revised figure). U.S. apparent consumption of primary nickel was 154,000 tons, or about 16% of Western demand. U.S. industry consumed an additional 68,800 tons of nickel in scrap. Both U.S. and world demand continued to be driven by the stainless steel industry. Stainless steel producers accounted for 40% of primary nickel demand in the United States and more than 60% of primary demand in the world.

The world market for stainless steel has become increasingly competitive since 1985. Production of raw stainless steel in the Western World has almost doubled in the past 12 years, growing from 7.92 million tons in 1985 to 14.91 million tons in 1996 (Inco Limited, 1997c). New production facilities have been started up in the Republic of Korea, South Africa, and Taiwan. At the same time, existing capacity has been expanded in Finland, France, Germany, Spain, and several other members of the EU. Stainless steel melting capacity in the Western World increased 15% just between 1995 and 1997 at a time when East Asia and several other regions began experiencing severe financial problems and a slowing of their economies. This expansion of capacity has been accompanied by a globalization of markets for both ferrous and nonferrous metals. Reduced growth in demand in several overseas markets has encouraged foreign stainless steel producers to increase their exports to the United States. Total U.S. imports of stainless steel mill products have doubled since 1992, while domestic production has risen only 20%. To remain competitive, the U.S. specialty steel industry has had to adopt more efficient work practices and become extremely innovative. U.S. specialty steel producers are increasingly substituting quality for tonnage.

Despite these factors, production of raw stainless and heat-resisting steel in the United States increased in 1997 by 12% to 2.16 million tons, breaking the previous record of 2.06 million tons set in 1995. Nickel-bearing grades accounted for 1.36 million tons, or 63% of the total stainless production for 1997 (American Iron and Steel Institute, 1998b). Net shipments of all types of stainless totaled 1.88 million tons (American Iron and Steel Institute, 1998a). Shipments of sheets and strip increased

9% to 1.36 million tons, breaking the previous record of 1.25 million tons just set in 1996. The next largest category was plate [flat product 4.8 millimeter (3/16 inch) or more in thickness]. Shipments of plate were 236,000 tons, 7% more than that of 1996. Together, plate and sheet accounted for 85% of total net shipments, essentially the same percentage as in 1996.

Stainless steel sheet is used in the manufacture of a wide range of consumer products, including household appliances, kitchen facilities, machinery, and medical equipment. Plate is primarily used in the fabrication of chemical reaction vessels and similar heavy-duty industrial equipment. The chemical, food and beverage, petrochemical, pharmaceutical, pulp and paper, and textile industries are all large consumers of stainless plate.

In 1997, U.S. consumption of primary nickel in superalloys increased by almost 20% because of growing orders in the aerospace industry. Jet engine manufacturers (e.g., General Electric Co., Pratt & Whitney Co., Inc. [subsidiary of United Technologies Corp.], and Rolls-Royce PLC) are significant consumers of nickel-chromium-cobalt and nickel-chromium-iron alloys. U.S. aerospace companies went through a difficult period from 1993 to 1995 because of declining defense spending, budget reductions at the National Aeronautics and Space Administration, and a protracted airline recession. In 1996, U.S. aerospace sales began to grow for the first time in 5 years. Sales rose 8% after falling in 1995 to their lowest level in 9 years. Sales were even better in 1997 and jumped 11% to $130 billion (Vadas, 1998). The aerospace market is now shifting from a government-dominated market to one driven primarily by commercial customers. The U.S. Government now accounts for only 50% of domestic aerospace products and services, compared with 75% a decade ago.

Passenger and freight traffic carried by world airlines have been increasing since 1993. For the third year in a row, the Boeing Company and McDonnell Douglas Corp. built up their backlog of orders for civil jet transports. A total of 512 net orders for large civil jet transports was received in 1997, compared with 595 in 1996 (Aerospace Industries Association of America, Inc., 1998). Actual shipments also increased between 1996 and 1997, rising from 269 aircraft to 374. On August 1, 1997, McDonnell Douglas merged with a subsidiary of Boeing. On December 31, the combined firms—operating under the name of The Boeing Company—had a backlog of 1,744 aircraft, up from 1,617 at yearend 1996. U.S. aerospace sales were expected to rise about 11% again in 1998, reaching a record $145 billion.

In 1997, the specialty steel industry of the United States found itself undergoing a major restructuring. U.S. superalloy producers, which have close ties to some of the specialty steel producers, quickly followed suit. In August 1996, Allegheny Ludlum Corp. and Teledyne Inc. merged to form one of the larger specialty metals producers in the world. Allegheny Ludlum, one of the larger producers of stainless steel in the Western Hemisphere, had been interested in acquiring the specialty metals operations of Teledyne for more than 10 years. Teledyne was, at the time, a conglomerate of defense and consumer products businesses, with strong segments in aviation, electronics, and specialty metals. The new entity was called Allegheny Teledyne Inc. The principal force driving the merger was the financial synergies that should be created after the specialty metals operations of the two companies are fully integrated (Norton and Pasztor, 1996).

In early 1997, the managment of Inco decided to focus on its core business—nickel mining—and sell off its alloys group. On June 11, 1997, Inco announced that it had agreed to sell its alloy manufacturing division to Blackstone Capital Partners II Merchant Banking Fund L.P. for approximately $410 million, excluding fees and expenses (Inco Limited, 1997a, 1998c; Ryan's Notes, 1997). The alloy manufacturing division—Inco Alloys International (IAI)—is one of the world's leading developers and producers of wrought nickel-base alloys. However, the sale was subject to a number of conditions, including antitrust clearance from the U.S. Department of Justice and approval from other regulatory authorities. Blackstone wanted to combine IAI with Haynes International, Inc., creating one of the larger producers of superalloys in the world (Coplan, 1997; Sacco, 1997). Blackstone, a merchant bank based in New York, owns approximately 80% of Haynes. Haynes, an Indiana-based company, produces Hastelloy X, Waspaloy, and a variety of other nickel-base high-performance alloys.

The IAI sale was to have closed in the fall of 1997, but ran into opposition. The proposed merger clearly would have made Haynes the dominant supplier of nickel-based alloys in a world market shared by some 60 companies. Some industry analysts argued, though, that the new Haynes would have encountered stiff resistance from a number of well-financed competitors, including: Allegheny Teledyne Inc., Cannon-Muskegon Corp., Carpenter Technology Corp., Howmet Corp., Special Metals Corp., and VDM Technologies Corp. (Ryan's Notes, 1998). The transaction eventually collapsed when approval could not be obtained from the antitrust examiners in the Justice Department (Inco Limited, 1998c). Inco had planned to use the $85 million after-tax gain from the sale to pay off part of the debt incurred in acquiring the Voisey's Bay deposit.

IAI has been supplying superalloys to the aerospace industry for more than 40 years from its plant in Huntington, WV. The plant is equipped with facilities for electric arc and air induction melting, vacuum induction melting, electroslag remelting, vacuum arc remelting, argon-oxygen decarburization refining, and mechanical alloying. The division also has operations in Hereford, England; Burnaugh, KY; Elkhart, IN; and Newton, NC. The Newton plant specializes in welding products. In 1995, IAI acquired a majority ownership of a plant in Epone, France, that manufactures electrical resistance alloy wire and ribbon.

IAI products are bought by a broad spectrum of industry, in addition to aircraft engine manufacturers, and have a myriad of applications, including those in chemical processing equipment, food handling equipment, turbines and related power generation machinery, flue-gas scrubbers, downhole tubing for oil and gas wells, petrochemical storage tanks, and piping systems of all types. Incoloy, Inconel, Monel, and Nimonic are well known trademarks for families of high-nickel alloys produced by IAI.

Demand for nickel-cadmium and nickel-metal hydride batteries continues to grow throughout all of North America and is being spurred by the rapidly expanding U.S. program for recycling industrial and household batteries, which makes the use of nickel-based batteries more environmentally acceptable. Both battery types are widely used in handheld power tools and a myriad of portable electronic devices, including compact disc players, pocket recorders, camcorders, cordless telephones, cellular telephones, scanner radios, and laptop computers. In 1997, the United States imported $687 million worth of nickel-cadmium batteries.

**Stocks**

Stocks of primary nickel maintained in the United States by foreign producers and metal-trading companies with U.S. sales offices decreased 5% from yearend 1996 to yearend 1997. On December 31, 1997, these stocks represented 30 days of apparent primary consumption. U.S. consumer stocks are broken out by form in Table 5.

LME stocks far exceeded U.S. consumer stocks between 1992 and 1994. However, in 1995, more than 100,000 tons of cathode was withdrawn from LME-approved warehouses in Rotterdam to meet growing consumption in the Western World. Rotterdam is one of the principal delivery points for Norilsk Nickel. The drawdown ended in August 1996 and LME stocks began building up during the succeeding 12 months. By September 1997, LME stocks had climbed back above the 60,000-ton mark. At this point, the buildup halted and stocks leveled off. On December 24, 1997, LME warehouses held 66,204 tons of nickel metal, of which 63,168 tons or 95.4% was in the form of cut cathodes. The remaining 4.6% consisted of 3,000 tons of briquets and 36 tons of pellets. The 66,204-ton total represented a drop of 56% from the alltime record high of 151,254 tons reached on November 24, 1994. Although the LME now has 25 warehouse sites scattered around the world that are authorized to hold nickel, most of the material continues to be stored at either Rotterdam or Gothenburg, Sweden.

**Prices**

Nickel producers had a disappointing year in 1997 despite a promising beginning. During the first quarter of 1997, the monthly LME cash price rose from $7,072 per ton ($3.208 per pound) to $7,896 per ton ($3.582 per pound). Internal demands within Russia for hard currency and the depressed state of the Russian stainless steel industry encouraged Norilsk Nickel to continue exporting the bulk of its production to the West. In May, exports of cathode from Norilsk Nickel began to exceed demand causing LME stocks to build up in Rotterdam. Increased output from producers in Canada, Cuba, and Finland added to the oversupply situation, further weakening prices.

In June, nickel prices started to deteriorate and began a slow and largely uninterrupted decline lasting more than 14 months. By December, the monthly LME cash had fallen to $5,945 per ton ($2.697 per pound). At the end of 1997, the economic downturn in East Asia triggered a slump in Japanese stainless steel production and a corresponding drop in Japanese nickel consumption that worsened in 1998. The East Asian economic crisis also affected stainless steel production in the Republic of Korea and Taiwan, further weakening nickel prices. Other reasons cited by analysts for the price decline were:

(1) growing exports of nickel-bearing scrap from Russia to the EU,

(2) economic difficulties hindering the growth of nickel consumption within Russia and other members of the Commonwealth of Independent States (Pirani, 1998),

(3) productivity improvements at RAO Norilsk Nickel and other primary nickel producers,

(4) the commissioning of several new nickel mines in Australia (van Os, 1998),

(5) the expansion of existing nickel production facilities in Europe, Indonesia, and North America,

(6) the use of more stainless steel scrap and less refined nickel in the production of austenitic stainless steel, and

(7) excessive world stocks of finished stainless steel—the largest end use for nickel (Mining Journal, 1998).

The last weekly price (for the week ending December 26, 1997) was $5,871 per ton ($2.663 per pound). The average annual price was $6,927 per ton ($3.142 per pound). The annual price was about 8% lower than the 1996 average of $7,500 per ton ($3.402 per pound). Record high consumption in the Western World failed to keep up with the supply buildup. In 1997, nickel supply in the Western World exceeded demand by approximately 24,000 tons—about 3% of Western World consumption.

**Foreign Trade**

U.S. net import reliance as a percentage of apparent consumption was 56% in 1997—slightly less than the percentage for 1996. Imports accounted for 100% of primary supply in 1997, if Government stockpile sales are excluded. All of the ferronickel produced by the Glenbrook Nickel Co. in 1997 was derived from imported ores. Canada, as usual, supplied most of the LME-grade unwrought metal. The second largest source of unwrought metal was Russia, edging out Norway for the first time in U.S. history. Since 1992, Norilsk Nickel has become an important source of nickel for the United States. In 1997, the United States imported 25,300 tons of cathode and 212 tons of powder and/or flake directly from Russia. Importers also brought in 56 tons of Russian nickel contained in ferronickel and 8 tons contained in nickel sulfate.

Record-high exports of Russian stainless steel scrap added to the downward pressure on nickel prices. However, most of the Russian scrap was consumed in the EU and did not enter the U.S. market. The EU imported 346,000 tons (gross weight) of stainless steel scrap from Russia in 1997, compared with 270,000 tons in 1996 and only 193,000 tons in 1995. The EU reported receiving only 69,400 tons of scrap from the United States, down from 81,100 tons in 1996 and 148,000 tons in 1995. The bulk of the stainless steel scrap brought into the United States—some 64,100 tons (gross weight)—came from Canada and Mexico. U.S. exports of stainless steel scrap increased 21% between 1996 and 1997 despite the loss of market share in Europe. The bulk of U.S. scrap went to meltshops in the Republic of Korea (31% of the total 370,000 tons for 1997), Spain (16%), Taiwan (13%), and Mexico (13%). The exported scrap contained an estimated 27,700 tons of nickel, up from 22,800 tons in 1996, based on the assumption that stainless scrap averages 7.5% nickel.

Four of the larger U.S. producers of specialty steels expressed concern about the country's continuing high level of specialty steel imports, which reached a record 797,000 tons in 1997. The four producers were Allegheny Teledyne Inc., Armco Inc., J&L Specialty Steel Inc., and Lukens Inc. (now Bethlehem Lukens). Stainless steel accounted for 624,000 tons, or 78% of the 797,000-ton total. Electrical steel constituted 14%; tool steel, 8% (Specialty Steel Industry of North America, 1998).

U.S. imports of stainless steel were 13% greater than those of 1996 and were expected to be even higher in 1998 because of the ongoing Asian financial crisis. In mid-1997, domestic stainless steel companies decided to file a series of antidumping and countervailing duty petitions with the U.S. Department of Commerce and the U.S. International Trade Commission. The first petition dealt with stainless steel wire rod and was filed on June 30. Three more petitions—dealing with stainless steel wire, plate, and sheet—were being drafted at yearend.

**World Review**

In 1996, the world's largest nickel producer was Russia's RAO Norilsk Nickel with Inco Limited close behind. The next two leading producers were Falconbridge Limited of Canada and WMC Limited of Australia. In 1997, a new contender was created when Billiton Business separated from Gencor Limited of South Africa and began merger talks with QNI Limited of Australia. The merger eventually brought together several established nickel operations under a single-management structure, creating the world's fourth largest nickel producer with a production capacity of about 60,000 tons per year. This amalgamation was accomplished in less than 3 years through a series of carefully planned mergers and acquisitions (Platt's Metals Week, 1997a).

In September 1994, Gencor acquired Billiton BV from the Royal Dutch/Shell Group. Gencor reportedly paid Shell $1.14 billion for the international mining, metals smelting, and trading company. At the time, Billiton had sizable alumina/aluminum operations in Australia, Brazil, and Suriname as well as a 52.31% interest in Cerro Matoso S.A., the Colombian ferronickel producer. The old Billiton operations were subsequently integrated with a number of Gencor's metals and minerals businesses in South Africa, greatly expanding the capabilities of the group.

In February 1997, Gencor increased its interest in Cerro Matoso to 98.88%, buying out the Government of Colombia's share after the Government decided to privatize the ferronickel producer. Shortly afterwards, Gencor's management took steps to spin off the bulk of the parent company's metals and minerals businesses. On July 17, Gencor's shareholders formally approved the splitup of the parent company (Billiton Plc., 1997a). Gencor retained only its precious metals interests, which now form the base of the Gencor Group. The rest of its mining and processing activities were reorganized and transferred to Billiton Plc.—a new, totally independent company headquartered in the United Kingdom. Billiton Plc. was granted a business license on June 2, 1997, and was listed on the London Stock Exchange on July 28.

In early June, Gencor's management agreed to merge Billiton's nickel operations with those of QNI Limited. QNI owns and operates the Yabulu nickel refinery near Townsville, Australia. Lateritic feed for the Yabulu refinery comes largely from independent mines in Indonesia, New Caledonia, and the Philippines. The refinery is currently processing limonitic ore averaging 1.5% nickel and 0.15% cobalt. In addition to Cerro Matoso, Billiton had a 50% interest in the Lake Johnson Joint Venture and a 37.5% interest in the Roundtop Joint Venture—two enterprises developing nickel sulfide deposits in Western Australia. On June 18, the directors of Gencor and QNI jointly announced that QNI would acquire 100% of Gencor's nickel business ("Billiton Nickel") in exchange for shares in the newly expanded QNI. The merger was approved by QNI shareholders in September (Billiton Plc., 1997b).

***Australia***.—Several key mining projects were launched during the second half of 1997. Some $3 billion has been committed to projects that will increase Australia's mine production capacity by more than 77,000 tons of nickel per year. Total mine production reached 124,000 tons of nickel in concentrate and was projected to increase to 195,000 tons in 1999.

WMC Limited continued to set new production records at its operations in Western Australia. In fiscal year ending June 30, 1998, the company produced 114,000 tons of nickel in concentrate—breaking all previous records for the sixth consecutive year (WMC Limited, 1998b). The new Mount Keith Mine northwest of Leinster was in its third year of operation and accounted for 37% of the total output, making it one of the larger metal mines in Australia. The Mount Keith concentrator treated approximately 11 million tons of ore grading 0.60% nickel during the 12-month period, recovering 42,000 tons of nickel contained in concentrate. The concentrate was being dried at Leinster and then shipped either to WMC's smelter at Kalgoorlie or to Outokumpu Oyj's refining and smelting complex at Harjavalta, Finland.

During the same 12-month period, WMC's other two mining operations—Kambalda and Leinster—produced 32,000 tons and 39,900 tons of nickel in concentrate, respectively. The recently expanded smelter at Kalgoorlie produced 103,036 tons of nickel in matte, far surpassing the 72,939 tons reported for the previous 12 months. A sulfuric acid recovery plant was commissioned at the smelter in July 1996 at a cost of A$186 million (US$121 million). The new plant reduced sulfur dioxide emissions by 82% in FY 1996-97 and allowed environmental constraints that prevented the smelter from operating at full capacity to be lifted (WMC Mining Limited, 1998a). WMC's nickel refinery at Kwinana produced a record 52,113 tons of metal in FY 1997-98, up 10% from 1996-97.

The Forrestania Mine near Varley, Western Australia, produced 7,900 tons of nickel in concentrates in calendar year 1997, down from 9,500 tons in 1996. The mining operation excavated 400,000 tons of ore averaging about 2% nickel. The open pit mine has 400,000 tons of proven reserves and an additional 700,000 tons of probable reserves, both grading 2.1% nickel (Outokumpu Oyj, 1998). Company geologists estimate that there are about 2.7 million tons of indicated resources, again averaging 2.1% nickel, in the immediate vicinity of the mine. Forrestania has been in operation since November 1992 and is owned by Outokumpu Mining Australia Pty. Ltd., a wholly owned subsidiary of Outokumpu Base Metals Oy and its parent, Outokumpu Oyj.

Outokumpu Mining Australia has three other projects under development in Western Australia—Silver Swan, Cygnet, and

Black Swan. All three are 50-50 joint ventures with Mining Project Investors Pty. Ltd. (MPI) of Australia. Because Outokumpu Oyj also owns 34% of MPI, it effectively has a 67% equity in each of the three projects. Silver Swan began producing concentrates on June 1, 1997. The new underground mine is scheduled to produce 12,000 tons per year of nickel in concentrates for at least 5 years, all of which will go to the Harjavalta smelter in Finland. Silver Swan has 200,000 tons of proven reserves with an exceptionally high grade of 9.2% nickel and 500,000 tons of probable reserves estimated to average 9.3% nickel (Outokumpu Oyj, 1998). The Cygnet deposit is roughly the same size as the Silver Swan and has 1.0 million tons of probable reserves grading 2.2% nickel. Black Swan has 7.0 million tons of inferred resources at 0.8% nickel (Outokumpu Oyj, 1998).

On October 21, 1997, Outokumpu Base Metals Oy became the sole owner of the Honeymoon Well project in Western Australia, buying out its partner—Rio Tinto Exploration Pty. Limited. Rio Tinto Exploration already had agreed on September 3 to sell its 65% interest in the project to Outokumpu, but various government approvals had to be obtained before the sale could proceed to settlement. Outokumpu also acquired Rio Tinto's interests in the nearby Barrack, Capital, and Wiluna Nickel joint ventures (Outokumpu Oyj, 1997a,c). The project will be managed by the company's local subsidiary, Outokumpu Mining Australia. The Honeymoon Well deposit is in the Shire of Wiluna, about 60 kilometers northwest of the giant Mount Keith Mine owned by WMC. According to Outokumpu, the Honeymoon Well deposit has 118 million tons of indicated resources, averaging 0.8% nickel at a cutoff grade of 0.5% nickel. An additional 10 million tons of resources, averaging 0.7% nickel, are inferred. The nickel is in the form of disseminated sulfides and would be recovered using bulk mining techniques similar to those employed at the Mount Keith Mine.

Outokumpu and Rio Tinto began jointly exploring the Honeymoon Well area in 1989. Advanced feasibility studies of the deposit have been underway since 1996. The proposed open pit mining operation would produce about 30,000 tons per year of nickel in concentrate. Development is expected to cost about A$400 million (US$290 million). The concentrates would most likely be exported to Harjavalta. Harjavalta is already receiving concentrates from Mount Keith and Outokumpu's own Forrestania Mine.

Several other mining projects were in various stages of development in Western Australia. In May 1996, Anaconda Nickel Limited completed its feasibility study of the Murrin Murrin laterite deposit, 55 kilometers east of Leonora, and decided to go ahead with the project. In October 1996, Glencore International AG of Switzerland paid $220 million to increase its stake in the Murrin Murrin project to 40%. According to Anaconda officials, infill drilling indicates that the deposit has at least 128 million tons of ore grading 1.01% nickel and 0.064% cobalt (Anaconda Nickel Limited, 1997).

A pressure acid-leaching plant was being built on-site to extract the nickel and cobalt directly from the lateritic ore. The extraction process is similar to the one used at the Moa plant in Cuba, producing a mixed sulfide precipitate containing about 55% nickel and 4% cobalt. The nickel-cobalt precipitate will be redissolved, allowing the two metal ions to be separated from one another by solvent extraction. After separation, the nickel—now dissolved in an ammoniacal solution—will be fed into an autoclave and reduced to a metal powder in a hydrogen atmosphere.

Construction of the open pit mine and pressure acid leach plant was expected to cost A$900 million, or about US$655 million. Fluor Daniel Australia Ltd. was responsible for the overall design and engineering. Sherritt International was supplying the technology for hydrometallurgically extracting the nickel and cobalt. Development was to be carried out in two stages, with production of metal scheduled to start in December 1998. At the end of the first stage, the proposed plant would be able to process about 3.75 million tons of ore per year, producing 31,500 tons per year of nickel in briquets; 13,500 tons per year of nickel in concentrate; and 3,500 tons per year of cobalt. The second stage would raise the capacity of the operation to 75,000 tons of nickel and 4,500 tons of cobalt.

The Cawse project is expected to be another low cost hydrometallurgical operation. Like Murrin Murrin, it will use pressure acid leaching and electrowinning technology. The near-surface deposit is owned by Centaur Mining and Exploration Limited. The total capital expenditure was expected to be about $A236 million (Minerals Gazette, 1998). The mine site is about 50 kilometers northwest of Kalgoorlie. Production was scheduled to begin in September 1998 at an initial rate of 8,700 tons per year of nickel and 320 tons per year of cobalt (in sulfides). According to Centaur officials, the deposit has 193 million tons of inferred resources averaging 0.7% nickel and 0.04% cobalt. Included in this figure are 9.9 million tons of high-grade ore averaging 1.5% nickel and 0.12% cobalt. In some zones, cobalt assays 0.5% (Metal Bulletin, 1998a; Minerals Gazette, 1998).

Development plans for several other laterite deposits in Western Australia were resurrected when the Goldfields natural gas pipeline was completed in late 1996. The 1,380-kilometer-long pipeline carries gas from offshore fields in the Canarvon Basin on the North West Shelf to iron ore operations in the Pilbara and then on to nickel and gold operations as far south as Kalgoorlie. The cheaper energy provided by the pipeline was expected to spur development of Bulong and several other nickel laterite deposits along its route. Construction of the pipeline was financed by the Goldfields Gas Transmission Joint Venture. The venture is jointly owned by WMC (62.7% equity), BHP Minerals Pty. Ltd. (11.8%), and Normandy Poseidon Ltd. (25.5%). Boral Energy, one of the gas suppliers using the pipeline, has agreed to supply gas on a daily basis to Murrin Murrin. Boral Energy would build, own, and operate an 80-kilometer spur line from Leonora to Anaconda's new extraction and refining facilities.

QNI Limited produced 26,100 tons of nickel metal at its Yabulu refinery in Queensland. The lower than expected output was the result of production disruptions caused by abnormally high rainfall in December and subsequent flooding of the Townsville area. The company was planning to eliminate several bottlenecks at Yabulu, which should increase the capacity of the refinery to 35,000 tons per year in the year 2000. Two additional roasters and a new cobalt plant were commissioned during the year. The company also renegotiated its 8-year ore supply contract with P.T. Aneka Tambang of Indonesia (QNI Limited, 1998a).

Calliope Metals Corporation was considering building a A$465 million nickel and cobalt processing plant at Gladstone. The 20,000- ton-per-year nickel operation would rely on laterite ore from New Caledonia.

***Brazil***.—Outokumpu's refinery at Harjavalta will be receiving about 10,000 tons per year of nickel in matte from Mineração Serra da Fortaleza (Mining Journal, 1997d). The Brazilian company recently began operating a new nickel mining and smelting complex in the State of Minas Gerais. The company is an associate of RTZ Mineração Ltda., a wholly owned subsidiary of Rio Tinto plc. Under the terms of the purchase agreement, shipments of matte will begin in 1998 and continue for at least 10 years. The 10,000 tons per year of nickel in matte represents the entire planned output of the Fortaleza operation.

The Fortaleza smelter was commissioned in December 1997 and was expected to reach the 10,000-ton-per-year production rate by April 1998. The project has cost $233 million as of February 1997. The mine reportedly has 10.4 million tons of reserves of sulfide ore, averaging 1.68% nickel, 0.33% copper, and 0.04% cobalt, and should have a life of more than 20 years (Mining Journal, 1997d). During the first 5 years, the ore will come from an open pit mine. An underground mine would be constructed at some point during the 5-year period to recover the deposit's deeper ores. In 2003, the operation would switch over to underground mining. The concentrator is designed to treat 550,000 tons per year of ore. A refinery was to have been built on-site, but this part of the project has been postponed indefinitely.

Outokumpu was heavily involved in the design and startup of the Fortaleza smelter. In October 1995, Outokumpu licensed its new proprietary Direct Nickel Smelting Technology to the Fortaleza de Minas project and agreed to help design and engineer the smelter's flash furnace. In March 1996, the licensing agreement was updated and expanded to cover construction supervision, startup assistance, and training (Outokumpu Oyj, 1996; 1997a).

***Canada***.—The Province of Newfoundland and Labrador was immersed in a "gold-rush" atmosphere, with significant exploration activity occurring at several locations (Heffernan, 1998). The development of the huge Voisey's Bay deposit in northeastern Labrador is expected to have a major impact not only on the Nain region, but also on the island of Newfoundland itself. The deposit is the most important base metal discovery in Canada in more than 30 years. The Voisey's Bay property is now controlled by Inco, which acquired the complex of ore deposits and prospects from its original owner, Diamond Fields Resources Inc., through a complicated series of financial and stock transactions between 1994 and 1996. The Labrador operation was being managed by Voisey's Bay Nickel Co. Ltd.—a former subsidiary of Diamond Fields that was converted into a wholly owned subsidiary of Inco.

The Voisey's Bay deposit is 35 kilometers southwest of the town of Nain and only 10 kilometers from a natural deep-water harbor that opens into the Labrador Sea. The principal ore minerals are pentlandite, chalcopyrite, and pyrrhotite. By mid-1996, three separate zones had been identified—the Ovoid, the Eastern Deeps, and the Western Extension. The three zones are associated with the Reid Brook Intrusion and, in plan view, are aligned over a distance of almost 6 kilometers. The Ovoid is in the middle. The Ovoid zone has an estimated 31.7 million tons of ore averaging 2.83% nickel, 1.68% copper, and 0.12% cobalt—all of which is amenable to open pit mining. Preliminary drilling of the Eastern Deeps zone has identified 52.6 million tons of resources at depth averaging 1.36% nickel, 0.67% copper, and 0.09% cobalt. The Western Extension contains another 20 million tons of resources but many more holes will have to be drilled before a reliable estimate of ore grades can be made (Inco Limited, 1998c). In Inco's latest reports, part of this third resource is now referred to as the Discovery Hill zone. In late 1996, drilling crews identified a fourth zone of mineralization—subsequently named the Reid Brook zone—about 2 kilometers west of the Ovoid. This fourth zone lies beneath, and is partly contiguous with the shallower zone of the Western Extension. Drill hole assays from the core of the Reid Brook zone range from 1.2% to 2.8% nickel (Inco Limited, 1998c).

In December 1997, Inco submitted an extensive environmental impact statement for the proposed mine and mill complex to the Provincial Government. However, the project has fallen behind schedule because of prolonged negotiations with the Inuit representatives and the Provincial Government and other legal complications. If these complications can be overcome before mid-1999, production of concentrate could begin in late 2001.

In November 1996, Voisey's Bay Nickel announced plans to build a major smelting and refining complex at Argentia, Newfoundland, to process the nickel-cobalt concentrate produced at Voisey's Bay. The Argentia complex could be in full production as early as 2002 if the nickel market improves and the necessary permits can be obtained in time from the Government of Newfoundland (Inco Limited, 1998c). When fully operational, the complex would be able to process 816,000 tons per year of sulfide concentrate and produce 122,000 tons per year of refined nickel and 3,000 tons of cobalt, making it the largest nickel operation outside of Russia. About 16,000 tons per year of copper would be produced at Argentia as a byproduct from the nickel-cobalt concentrate.

The nickel-copper-cobalt ore mined at Voisey's Bay would be milled on-site. The Voisey's Bay mill would have a differential froth flotation circuit and produce two concentrates—one of pentlandite and one of chalcopyrite. Only the pentlandite concentrate would go to Argentia. The current plan calls for the chalcopyrite concentrate to be toll smelted elsewhere for economic reasons. Production of concentrate was originally scheduled to begin in late 1999, but will be delayed at least 2 years (Inco Limited, 1998c). About 80% of the copper in the ore would end up in the chalcopyrite concentrate. This second concentrate would yield only about 75,000 tons per year of copper. A viable, dedicated copper smelting and refining operation would require considerable more copper concentrate than that projected from Voisey's Bay.

At Argentia, Inco would convert the pentlandite concentrate into a pebble-sized, granulated nickel sulfide matte, using proprietary flash smelting technology developed in-house (Voisey's Bay Nickel Company Limited, 1996). The oxygen flash smelting produces a crude iron-nickel-copper matte that has to be processed further in a converter to remove the bulk of the iron. In the converter, oxygen is blown up through the molten matte, oxidizing the iron. The oxidized iron then enters the overlying silicate slag layer. After separation of the iron, the nickel-rich matte left in the converter—the Bessemer matte—is ready to be refined.

Sumitomo Metal Mining Co. Ltd. of Japan has agreed in principle to license its patented matte chlorine leach electrowinning (MCLE) process to Inco. Inco wants to use the hydrometallurgical process in the refining part of the complex. Bessemer matte has three principal components—trinickel disulfide ($Ni_3S_2$), nickel-copper alloy, and cuprous sulfide ($Cu_2S$). The MCLE process would be used to leach the nickel, copper, and cobalt from the matte, leaving behind elemental sulfur in a solid phase while simultaneously separating the copper from the nickel and cobalt. The sulfur would be drawn off, melted, filtered, and then pumped back to the smelter's sulfuric acid plant where it would be burned to sulfur dioxide and added to the off-gas feed stream from the flash furnace.

The MCLE process uses the cupric-cuprous redox couple to separate the nickel from the copper. A detailed description of the process is given in Ishikawa, 1994. Sumitomo has been using the MCLE process to produce high-quality nickel metal and cobalt at its Niihama refinery in Ehime Prefecture, Japan, since 1992. The process is carried out in a closed system, making it environmentally friendly. The first refined nickel would be available from Argentia in late 2001, with full production in 2002. Sumitomo and Inco have been cooperating on projects for more than a decade.

Argentia is on tidewater and close to some major North Atlantic shipping lanes, permitting Voisey's Bay Nickel to economically supplement its feedstocks with nickel concentrates purchased on the world market. The site also is relatively close to inferred resources of nickel sulfides being evaluated in the Lac Manitou, Sept-Îles, and Gaspé regions of southeastern Quebec as well as in parts of Maine. All four regions could conceivably supply additional nickel concentrates for the smelter.

Several other mining companies were actively prospecting for nickel and related base metals in the Nain region. In September 1997, drilling crews employed by Teck Exploration Limited began intersecting significant nickel-copper-cobalt mineralization on claims shared equally by Donner Resources Limited and Northern Abitibi Mining Corp. The claims are about 90 kilometers south of the immense Voisey's Bay nickel deposit. The diamond drilling project is part of a much larger regional exploration program put together by a consortium of relatively small Canadian exploration companies and supported by Teck (Brockelbank, 1997). Donner acquired extensive claims in the area in early 1995. Since then, Donner has obtained additional holdings by forming joint ventures with 13 other exploration companies. These holdings form the South Voisey's Bay (SVB) Project and now total about 1,500 square kilometers (Donner Resources Limited, 1997a).

During the 1995 and 1996 field seasons, Donner focused its exploration efforts on several large gabbroic intrusions that contained low but significant copper, nickel, and cobalt values. These layered intrusions are geologically similar to the host rocks associated with sulfide mineralization at Voisey's Bay. Each of the SVB intrusions has a thick upper layer of coarse-grained gabbro. The thinner, lower layer of each intrusion is composed of a fine-grained olivine gabbro called troctolite. Preliminary drilling indicates that pentlandite, chalcopyrite, and other sulfides were deposited in a zone along the contact between the intruding troctolite and the underlying country rock—a sulfide-rich, graphitic gneiss.

In the SVB project area, 32 holes have been drilled to date. Drill hole 97-67 intersected three separate, but thin, zones of massive sulfides between 176 and 180 meters downhole near the contact with the gneiss. The average grades of the three zones ranged from 1.35% to 1.93% nickel, along with 0.84% to 1.64% copper. Each of the three zones was less than 0.6 meters thick. A second drill hole—No. 97-75—subsequently intersected a 1.1 meter-thick section of massive sulfides that assayed 11.75% nickel, 9.70% copper, and 0.43% cobalt. This second mineralization occurred at a depth of 177 meters—13 meters below the base of the intrusion—and contained visible pentlandite (Donner Resources Limited, 1997a, South Voisey's Bay project update: Donner Resources Limited press release, October 29, 7 p. Accessed November 7, 1997, at URL http://www.donner-resources.com/pr102997.htm).

In early 1997, Donner retained Teck Exploration Limited as its general contractor for the upcoming field season, budgeting more than $5 million for a diamond drilling program and followup geological and geophysical work. As part of the contracting agreement, Teck Corporation—the exploration company's parent—was given warrants for 1.4 million shares of Donner stock. On October 20, Teck exercised these warrants, acquiring the 1.4 million shares for C$2.8 million, or C$2.00 per share. As a result of the exercise, Teck now holds 2.8 million shares of Donner stock, giving Teck a 12.2% interest in the company. Teck also had warrants to purchase an additional 1.4 million shares on or before October 18, 1998. Under the terms of the agreement, Teck can earn a 50% interest in any of Donner's interests in the SVB Project (Donner Resources Limited, 1997b, Teck Corporation exercises warrants: Donner Resources Limited press release, October 20, 1 p. Accessed November 7, 1997, at URL http://www.donner-resources.com/pr102097.htm).

The Voisey's Bay discovery has spurred nickel exploration throughout other parts of Eastern Canada as well and heightened expectations of a number of small exploration companies. In August 1996, a team of geologists employed by the Provincial Government of Quebec encountered two gossans while mapping part of the Lac Manitou-Lac Nipisso area. The discovery was made near Lac Volant, a smaller lake east of Lac Nipisso. Lac Volant is about 60 kilometers northeast of the iron ore port of Sept-Îles and lies within the Grenville structural province of the Precambrian Canadian Shield. As soon as officials of the Quebec Government learned of the find, they temporarily withdrew 800 square kilometers of land surrounding the gossans from staking. Government geologists then staked more than 130 claims for the Crown within the withdrawn parcel. St. Geneviève Resources Ltd. and Virginia Gold Mines Inc., already exploring in the area, quickly staked more than 1,000 claims around the perimeter of the withdrawn area. Surface samples from a number of these claims showed enrichment of copper, nickel, and cobalt.

On October 9, 1996, the Quebec Government lifted its ban, triggering a staking rush along the entire North Shore of the St. Lawrence estuary. Other companies currently exploring the

North Shore include Azimut Exploration Inc., Falconbridge Limited, Fancamp Resources Limited, GeoNova Explorations Inc., Inco Limited, Kennecott Canada Inc., and Vior Mining Exploration Co. Inc. The drilling results to date have been disappointing. If the Lac Manitou area should turn out to be a significant resource of nickel, sulfide concentrates could be shipped relatively easily across the Gulf of St. Lawrence to Argentia. Lac Volant is only about 15 kilometers from the Quebec North Shore and Labrador Railway, which operates between Sept-Îles and the iron mines near Labrador City.

Significant development work and exploration activity continued in northern Quebec. On December 10, 1997, Falconbridge Limited began producing nickel-copper-cobalt concentrates at its new Raglan Mine. Startup was 3 months earlier than originally planned. The greenfield mining and milling complex is at the tip of the Ungava Peninsula. The site is near Katinniq, a village in the Monts de Povungnituk area, 60 kilometers west of Kangiqsujuaq and 100 kilometers southeast of Salluit. Falconbridge has spent more than C$500 million on development and construction. More than 150 people now live at the remote site. Falconbridge also has tried to maximize involvement of the local Inuit people in the project. The company has been working closely with local communities, their overseeing Makivik Corporation, and the Kativik Regional Government to resolve potential environmental and economic development issues as they arise. Part of the profits from Raglan will go into a trust fund for the Inuit (Falconbridge Limited, 1997b).

Raglan was expected to be fully operational by mid-1998 and will increase the company's production of nickel in sulfide concentrates by almost 50%. Ore will come from several open pits and an underground mine at Katinniq. The mill was assembled on-site from 12 prefabricated modules, each weighing up to 1,200 tons (Falconbridge Limited, 1997c). The modules were constructed at the Port of Quebec, shipped by barge to Deception Bay on the Hudson Strait, and then hauled on special transporters 95 kilometers to Katinniq. The mill can process 2,400 tons of pentlandite-chalcopyrite ore per day. By the end of 1998, the complex will probably be able to produce 130,000 tons per year of concentrates typically grading 16% nickel and 4% copper. This capacity figure equates to 20,800 tons of nickel; 5,200 tons of copper; and 200 tons of cobalt (Falconbridge Limited, 1997b). The concentrates also contain economically recoverable amounts of platinum-group metals.

The concentrates will be trucked to Deception Bay and from there shipped by vessel to Quebec City. From Quebec City, the concentrates will be railed to Falconbridge's smelter at Sudbury, Ontario, for conversion into matte. The matte will then be railed back to Quebec City and shipped to Falconbridge's Nikkelverk refinery in Norway where the metals will be separated from one another.

According to company officials, the Raglan Mine has 17.2 million tons of proven and probable reserves, averaging 3.12% nickel and 0.87% copper (Falconbridge Limited, 1998a). The mine has an additional 4.8 million tons of possible reserves averaging 2.87% nickel and 0.86% copper. Falconbridge had been planning to produce 21,000 tons per year of nickel in concentrate over the first 15 years of operation. However, recent drilling has identified three new zones of mineralization, adding 1.3 million tons of resources to Raglan's ore reserves. The additional reserves may permit Falconbridge to increase Raglan's capacity in the future to 30,000 tons per year of nickel. All of the ores occur in the northeastern half of the Proterozoic Cape Smith Fold Belt. The fold belt extends across the entire width of the Ungava Peninsula, from Cape Smith on Hudson Bay to Kangiqsujuaq (Picard and others, 1990). The fold belt is apparently part of a Precambrian rift system that first accumulated continental shelf sediments and continental flood basalts, and later oceanic basalts. Andesites, pillow lavas, and volcanic breccias are also common. The northern half of the fold belt appears to be a vast ophiolitic complex. The entire belt is permeated by southwest-northeast trending dikes of diabase, gabbro, and peridotite.

Geologists have identified more than 15 nickel-copper deposits in the northeastern part of the Cape Smith Fold Belt. The pentlandite-chalcopyrite-pyrrhotite ore bodies are associated with basaltic sills and flows and are thought to have segregated from the magnesium-rich, ultramafic magma during cooling (Barnes and others, 1992). Falconbridge's holdings extend along a 55-kilometer east-west strip in the Cross Lake-Katinniq-Raglan-Donaldson area and include several ore bodies that have not been fully explored.

At the present time, there is considerable exploration activity south of the Raglan property. In May 1997, Canadian States Resources Inc. entered into an agreement with Ungava Minerals Corp. to drill a promising nickel-copper deposit 12 kilometers south of the Raglan property. In August, High North Resources Inc. began drilling for massive sulfides in the Expo Ungava Zone. This second drilling program was also being conducted under an option from Ungava Minerals. High North was hoping to intersect massive sulfide bodies associated with peridotite intrusions (High North Resources Inc., 1997, High North Resources Inc.-Drilling commences at Expo Ungava: Canada News Wire, High Resources Inc. press release, August 14, 1 p. Accessed March 27, 1998, at URL http://www.newswire.ca/releases/August1997/14/c2565. html). The Expo Ungava area was drilled by AMAX Inc. during the 1970's. At that time, AMAX reported finding 4.2 million tons of resources grading 0.75% nickel and 0.85% copper that could be exploited by open pit mining with a waste to ore ratio of 2.75:1 (Canadian States Resources, Inc., 1997, Agreement reached on nickel copper property south of Falconbridge's Raglan property in Quebec: Canada News Wire, Canadian States Resources Inc. press release, May 16, 1 p. Accessed March 27, 1998, at URL http://www.newswire.ca/releases/May 1997/16/c3834.html).

In the Sudbury Basin of Ontario, Falconbridge was in the process of bringing its previously idled Lockerby Mine into full production. In 1997, the mine produced 143,000 tons of ore averaging 2.18% nickel and 1.09% copper—containing some 3,100 tons of nickel and 1,500 tons of copper. Falconbridge had four other nickel-copper mines operating along the rim of the basin—the largest being the Onaping/Craig complex. Underground exploration drilling at Onaping/Craig since 1995 has identified significant additional sulfide mineralization. In 1997, Falconbridge extracted 2.76 million tons of ore averaging 1.68% nickel and 1.79% copper from its five mines in the basin. The company's smelter at Falconbridge recovered 44,563 tons of nickel and 18,458 tons of copper in matte made from the mined ores and custom feed (Falconbridge Limited, 1998a).

Inco's new McCreedy East Mine at Sudbury came on-line in 1996 and should be in full production by 1999. McCreedy East is one of the company's lower-cost mines in Canada and, when fully operational, will have an annual production capacity of 11,000 tons of contained nickel and 28,000 tons of contained copper. At yearend 1997, Inco's Victor Deep exploration shaft on the northeastern edge of the basin had reached its planned depth of 1,460 meters. Underground exploration drilling outward from levels near the bottom of the shaft was in progress. With the help of computerized equipment, crews drilled more than 53,000 meters of core during the year. A new ore zone was discovered on the 1,460-level about 180 meters south of the main ore zone. Preliminary analysis of the drill data indicates that the Victor Deep deposit may have more than 20 million tons of ore resources (Inco Limited, 1998a). In late 1997, Inco announced that it was planning to temporarily shut down the McCreedy West, Levack, and Little Stobie Mines in 1998 because of declining nickel prices. McCreedy East, Copper Cliff North, Copper Cliff South, and Creighton would all continue to operate.

In Manitoba, Inco continued to deepen its Birchtree Mine and fully develop its 1-D ore body. The Thompson Mine and part of the Birchtree Mine were to remain open in 1998. At yearend 1997, Inco's Canadian operations had 356 million tons of ore reserves. Of the 356 million tons, 249 million tons were located at producing mines. The 249 million tons of reserves contained 3.9 million tons of nickel and 2.8 million tons of copper, which are equivalent to an average grade of 1.6% nickel and 1.1% copper (Inco Limited, 1998c). The remaining 107 million tons of reserves were associated with the Voisey's Bay deposit in Labrador, other mines under development in Manitoba and Ontario, nonproducing mines, and undeveloped properties.

***Colombia***.—In February 1997, the Government of Colombia sold all of its remaining holdings in Cerro Matoso S.A. (CMSA) to its partner, Gencor Limited of South Africa. CMSA operates an open pit laterite mine and smelter near Montelibano in the Department of Cordoba. The Government had been planning to privatize CMSA for some time. The award was made in Bogota at the conclusion of an open auction hosted by Colombia's three stock exchanges on February 18. The auction was supervised by Sociedad Fiduciaria Industrial S.A., a branch of the Government's Industrial Development Institute.

The sale increased Gencor's equity in the ferronickel producer from 52.31% to 98.88%. The remaining 1.12% of the shares was held by CMSA employees, together with employee unions. Gencor paid the Government of Colombia 178 billion pesoes, or about $166 million, for its holdings (Billiton Plc., 1997a). In 1997, CMSA was paying the Government a royalty of 8% of the gross value of the ferronickel extracted less processing costs. As part of the sales agreement, CMSA gained rights to exploit the concession until 2026 and has an option to extend these rights to 2041.

In 1997, the Cerro Matoso smelter produced 25,171 tons of nickel contained in ferronickel bars and granules, breaking the old record of 24,565 tons set in 1995. In past years, the nickel content of the ferronickel has typically ranged from 39% to 43%, but some of CMSA's most recent material reportedly averages 46%. The company exported 25,686 tons on a contained basis in 1997, 63% of which went to Europe. In 1997, significantly more material went to Asia than in 1995 and 1996. The Republic of Korea bought 17% of CMSA's 1997 exports—4,325 tons on a contained basis—while Taiwan became a customer for the first time, taking 3,008 tons or 12%. Only about 6% of the company's exports went to the United States (International Nickel Study Group, 1998c). The smelting process used by CMSA is very energy intensive. Electricity accounted for approximately 28% of the company's cash production costs in 1996. As of June 30, 1996, CMSA had 31.3 million tons of proven ore reserves averaging 2.5% nickel and 14.1 million tons of probable reserves averaging 2.2% nickel (Billiton Plc., 1997a).

***Côte d'Ivoire***.—For the past 5 years, Falconbridge Limited has been evaluating several laterite deposits northeast of Mount Nimba where the borders of Côte d'Ivoire, Guinea, and Liberia intersect. In December 1996, Falconbridge signed a memorandum of understanding with the Government of the Côte d'Ivoire that outlined a schedule for further project work. The project is part of a joint venture with Trillion Resources Ltd. of Kanata, Ontario, and the Société d'État pour le Développement Minier de la Côte d'Ivoire (SODEMI). Much of the work has focused on pyroxenites in the highlands region between Biankouma and Touba, northwest of Man. Additional lateritic material was identified during the 1997 diamond drilling program, increasing total known resources to 293 million tons (Falconbridge Limited, 1998a). The resources have an average grade of 1.46% nickel and 0.11% cobalt. Falconbridge has an option to earn a 60% interest in the project. SODEMI and the Government of the Côte d'Ivoire would have 25%; Trillion, 15%.

In June 1997, the results of a hydrometallurgical scoping study were presented to the joint-venture partners and the Government of Côte d'Ivoire, launching a new stage of discussions about the project's future (Trillion Resources Ltd., 1998). Sipilou North would most likely be the first deposit exploited. The proposed hydrometallurgical process would enable cobalt to be recovered along with the nickel, making the project more economically feasible. A miniscale pilot plant has been constructed at Sudbury, Ontario, to treat bulk samples and further improve process technology. The Government of Côte d'Ivoire has hired an independent consultant to help it assess the scoping study and evaluate the economic impact of the project (Trillion Resources Ltd., 1998). Key issues dealing with the development of transportation infrastructure and a fiscal regime still need to be resolved. By the fall of 1998, Falconbridge should be in a position to decide whether to proceed with a full-scale feasibility study.

***Cuba***.—Metals Enterprise continued to modernize the Moa mining and mineral processing facility in Holguín Province. The vertically integrated enterprise is a 50-50 joint venture between General Nickel of Ciudad Habana and Sherritt International Corp. of Toronto, Canada. Cuba's other nickel processing plants—Nicaro and Punta Gorda—are not part of the joint venture. In 1997, the Moa facility produced 26,512 tons of nickel and cobalt contained in mixed sulfides—a new record. The output was more than double the 12,549 tons reported for 1994 when the joint venture was formed (Sherritt International Corporation, 1998). The sulfide precipitate was being shipped from Moa Bay via

Halifax, Nova Scotia, to the joint venture's nickel-cobalt refinery at Fort Saskatchewan, Alberta. In 1997, the Fort Saskatchewan refinery produced 25,600 tons of nickel (in metal powder and briquets) and 2,300 tons of cobalt. This was the highest output in the refinery's 43-year history, breaking the previous record set in 1996.

Metals Enterprise was spending approximately $165 million to rehabilitate and upgrade the Moa facilities. By 1999, the Moa facility was expected to produce 27,000 tons of contained nickel plus cobalt per year. A pressurized leach process is being used to extract the two metals from the goethite ore. The process is relatively efficient, recovering more than 90% of the nickel, but it consumes large amounts of sulfuric acid. Almost one-third of the modernization money was being used to replace the three existing acid plants with a single modern unit capable of producing 1,500 tons of acid per day. Two of the plants were still operating on an interim basis; the third was closed in 1995. Overhaul of one acid plant was completed in 1996; the second was finished in early 1997.

On July 10, 1997, KWG Resources Inc. (a Montreal-based exploration company) and Commercial Caribbean Nickel S.A. (CCN; a parastatal enterprise of the Cuban Government) announced plans to jointly develop the Cupey lateritic nickel deposits in Holguín Province (Mining Journal, 1997b). The Cupey deposits reportedly contain 107 million tons of lateritic and serpentine resources grading 1.32% nickel and 0.115% cobalt, based on a cutoff grade of 1.0% nickel. Some 22 million tons are proven and another 85 million tons are probable. The resource calculations were made by Geominera S.A.—another parastatal organization that oversees the Cuban mineral industry—and verified by an independent Canadian engineering firm (KWG Resources Inc., 1997a). Metallurgical test work on bulk samples suggests that nickel recovery would be in the range of 84% to 87%. If completed, the Cupey project could produce over 30,000 tons of nickel and 1,400 tons of cobalt annually for at least 25 years. CCN and KWG had planned to complete the partially built ore processing plant at Las Camariocas as part of the Cupey project. The Las Camariocas facility is about 75% complete and has been on a care-and-maintenance basis for 6 years.

Under an agreement signed on July 5, 1997, CCN was to have contributed the deposits and the existing processing infrastructure. KWG was to have been responsible for raising the $325 million needed to finance the project (KWG Resources Inc., 1997c). More than a fifth of the money—some $70 million—was to have been used to construct a refinery in Canada. All work on the Cupey project was suspended at the end of 1997. KWG had difficulty raising funds for the project and was forced to withdraw from the arrangement because of stagnating gold prices and a decrease in the price per share of the company's stock. The Canadian company was forced to shelve several other projects, downsize operations, and restructure. This difficult situation was further aggravated by declining nickel prices, which made it harder to raise development money (KWG Resources Inc., 1997b).

At least two other prominent nickel producers have entered into agreements with Cuban parastatal organizations since 1993. Gencor Limited of South Africa has started to evaluate a lateritic deposit in the San Felipe area of Camaguey Province. Under the contract negotiated between Cuban authorities and Gencor, San Felipe Mining BVI Limited (a subsidiary of Gatro Caribbean Investments Limited) was to have earned a 75% share in the project by spending a minimum of $350,000 on fieldwork and by completing other undisclosed exploration and evaluation tasks (QNI Limited and Billiton Plc, 1997). Gencor's interests in the project were transferred to the new QNI organization in late 1997 when QNI merged with the nickel division of Billiton Plc. Concerns about the merger and declining nickel prices apparently delayed funding of the fieldwork.

In September 1994, Western Mining Corporation Holdings Limited of Australia (now WMC Limited) signed a memorandum of understanding with Commercial Caribbean Nickel to evaluate and develop the Pinares de Mayari West lateritic deposit in Holguín Province. Negotiations continued for another 3 years. At yearend 1997, WMC and the state-owned enterprise were in the process of finalizing the details of their joint venture. The Pinares deposit reportedly contains more than 200 million tons of ore exceeding 1% nickel and 0.1% cobalt (WMC Limited, 1997, 1998c,d). WMC was planning to use high-pressure leaching technology developed by Sherritt International to recover the nickel and cobalt (Metal Bulletin, 1996). The overall hydrometallurgical process will be similar to the one currently employed at Moa.

***Dominican Republic***.—Falconbridge Dominicana, C. por A., (Falcondo) produced 32,425 tons of nickel in ferronickel, breaking the previous record of 32,110 tons set in 1994. The ferronickel typically contains 38% nickel and is cast into gumdrop-like ferrocones, a form that makes bulk transportation and handling easier for the customer.

On December 31, 1997, Falcondo had proven, probable, and possible ore reserves totaling 61.5 million tons and averaging about 1.56% nickel. Over the past few years, the grade of the laterite mined at Bonao has gradually declined, requiring more ore to be fed to the furnaces. To counter the dropoff in nickel content, Falcondo has begun developing an improved circuit for upgrading the laterite prior to reduction in the electric arc furnace. The process, which grinds the ore more finely, is still at the pilot-plant stage but could increase annual production by 4,000 tons of nickel in ferronickel, while simultaneously lowering operating costs. If successful, the cutoff grade for the mine could be lowered from 1.2% nickel to 1.0%, increasing ore reserves by more than 60% and extending the life of the mine from 21 to 33 years (Falconbridge Limited, 1997a). Substantial pilot work was carried out in 1997, but some parts of the process had to be taken back to the bench scale level (Falconbridge Limited, 1998a).

***European Union***.—**European Commission**.—The European Commission has proposed new environmental legislation that would ban the use of cadmium in batteries throughout the EU after the year 2008 (Trickett, 1998). The proposed directive (93/157/EEC) was being supported by Sweden and several other Member States in northern Europe concerned about human exposure to the toxic metal. If implemented, the directive would put the low-cost end of the rechargeable battery market into turmoil. Rechargeable nickel-cadmium batteries currently account for about 70% of world cadmium consumption and are still cheaper to manufacture than their newer lithium-ion and nickel-metal hydride counterparts. Under the Amsterdam Treaty of June 17, 1997, the directive must still be adopted by both the Council of Ministers and the European Parliament. The International Cadmium Association, several primary zinc refiners, and some key battery manufacturers have opposed the directive. To support its argument, the International Cadmium Association cited the successful recycling programs for nickel-cadmium batteries in the EU, Japan, and the United States. Spokespersons for the association also pointed out that cadmium emissions into the environment have been declining since the 1960's because of increased recycling and improvements in pollution control technology. As a result, the cadmium intake for the general population has fallen significantly over the past 20 years and is approaching preindustrial levels (International Cadmium Association, 1998).

***European Union*.—Finland**.—In 1995, Outokumpu Base Metals Oy completed a major expansion of its Harjavalta smelter and refinery in Turku-Pori Province, Finland. The expansion raised the production capacity of the complex to 32,000 tons per year of nickel briquets and cathode and 160,000 tons per year of blister copper. In 1997, parts of the smelter and refinery were still in a startup mode and were experiencing operational problems related to the expansion (Outokumpu Oyj, 1998). In June, an explosion occurred in the slag furnace of the nickel smelter. In July, the vault of the copper flash furnace was damaged. Despite these problems, Harjavalta produced 35,300 tons of nickel and 159,000 tons of blister copper—a dramatic increase in comparison with 1995 when interruptions linked to the expansion caused output to drop to 18,400 tons of nickel and 88,300 tons of copper. Plans have already been drawn up to increase the annual production capacity of the smelter to 40,000 tons of nickel.

Outokumpu Base Metals has only one nickel mine still operating in Finland—the Hitura Mine near Ainastalo. Because of declining ore reserves, the Vammala Mine was closed in January 1995. In 1997, the Hitura Mine produced 2,500 tons of nickel in concentrate, compared with 3,100 tons in 1996. According to company records, at the end of 1997, the Hitura Mine had 700,000 tons of proven and probable reserves, averaging 0.74% nickel (Outokumpu Oyj, 1998). The mine had an additional 5.5 million tons of measured, indicated, and inferred resources containing 0.7% to 0.8% nickel. Since March 1995, the Harjavalta smelter has relied mainly on concentrates from WMC's new Mount Keith Mine and Outokumpu's own Forrestania Mine, both in Western Australia. In June, the Silver Swan Mine also began shipping concentrate to Harjavalta from Western Australia.

Outokumpu took a number of steps to lock up future supplies of nickel concentrate and matte for Harjavalta. The Fortaleza smelter in Brazil, the Honeymoon Well deposit in Western Australia, and the Pechenga area of the Kola Peninsula were expected to be important sources of feed for Outokumpu after the year 2000. (For details, see sections on Australia, Brazil, and Russia.)

***Indonesia***.—P.T. International Nickel Indonesia (P.T. Inco) was in the midst of a major expansion of its mining and smelting complex on the island of Sulawesi. The $580 million expansion will take an additional 3 years to complete and raise the production capacity of the Soroako smelter from 45,000 tons per year of nickel in matte to 68,000 tons per year (P.T. International Nickel Indonesia, 1998). P.T. Inco officials approved the expansion after the Government of Indonesia agreed to modify the company's Contract of Work and extend the contract to the year 2025. The original contract, signed in 1968, was due to expire in 2008. The new Contract of Work was formally signed in Jakarta on January 15, 1996. The bulk of the additional production was expected to be consumed in Asia—the fastest growing market for nickel at the time of the agreement (Upton, 1998).

P.T. Inco produced 35,496 tons of nickel in matte in 1997, down 10% from the 39,503 tons reported for 1996. One of the three electric arc furnaces at Soroako was damaged in an eruption on September 10, 1996, and had to be rebuilt. The furnace did not come back on-line until December 1996 and did not reach full production until the end of June. Production was limited in the second half of 1997 by a prolonged drought that resulted in power shortages at the smelter. The Soroako operation derives its power from a 165-megawatt hydroelectric plant on the Larona River. The company has since deepened the river channel from the feeder lake to the dam to improve water flow and permit power generation even when the lake level is excessively low. Increased rainfall at the very end of 1997 allowed the company to raise production levels to 70% of capacity, currently 52,200 tons of nickel in matte. A second hydroelectric plant—now under construction as part of the expansion program—was not scheduled to begin operating until late 1999. The new $130 million facility will provide an additional 93 megawatts of generating capacity.

The matte, which averaged 78% nickel, was being shipped to Tokyo Nickel Company, Ltd. at Matsuzaka, Japan, for conversion into oxide sinter and utility nickel. The refining capacity of the Matsuzaka facility was being expanded by 50% to handle the additional output from Soroako. By late 1998, the Matsuzaka facility should be able to process 54,000 tons per year of nickel (Inco Limited, 1998c). Inco Limited, which owns 59% of P.T. Inco, also has a 51% interest in Tokyo Nickel.

In August 1996, BHP Minerals Limited of Australia and P.T. Aneka Tambang of Indonesia formed a joint venture to evaluate lateritic nickel prospects on Gag Island, Irian Jaya. Gag Island is about 130 kilometers southeast of Halmahera, Maluku, and 150 kilometers northwest of Sorong at the northwestern tip of Irian Jaya. The nickel prospects on Gag Island have been known for some time and are currently held by Aneka Tambang. Prior to 1997, Aneka Tambang was a wholly state-owned mining enterprise. The joint venture is hoping that advanced recovery technologies developed by BHP will make the Gag project economically feasible. BHP has a 75% interest in the Gag Island venture and has already submitted a Contract of Work to the Government of Indonesia. The initial feasibility study should be completed by January 1999.

Gag Island is only 40 kilometers southeast of Gebe Island, Maluku, where Aneka Tambang has one of its two principal nickel mines. The other mine is near the company's ferronickel smelter at Pomalaa in southeastern Sulawesi. The Gebe Island Mine has been in operation since April 1979 and is currently shipping ore to Pomalaa, QNI Ltd.'s Yabulu Refinery in Queensland, Australia, and Japanese ferronickel producers. The Gebe Island Mine has 27 million tons of reserves averaging 2.2% nickel (BHP Minerals Limited, 1996). Aneka Tambang shipped

1.24 million wet tons of high grade ore and 1.21 million wet tons of low grade ore from the two mines in 1997. The Government of Indonesia was in the process of partially privatizing Aneka Tambang. The initial public offering of 431 million shares was made in November (P.T. Aneka Tambang, 1998). A portion of the funds from the stock flotation would be used to expand the Pomalaa smelter. In 1997, the Pomalaa smelter produced 9,999 tons of nickel in ferronickel, up slightly from 9,397 tons in 1996.

***New Caledonia***.—Société Métallurgique Le Nickel (SLN) operated four nickel mines on the island in 1997—Thio, Kouaoua, Népoui-Kopéto, and Tiébaghi. A fifth mine, Etoile du Nord (also known as Kaala-Gomen), was being operated by contractors. Tiébaghi, a new mining operation, began shipping ore in the fourth quarter of the year. The new Kiel pit, on the periphery of Kouaoua, reached its designed capacity. SLN and its subcontractors mined 2.94 million tons of wet lateritic ore, slightly less than in 1996 because of unfavorable weather and the political disruptions described below. Mines operated directly by SLN accounted for 2.31 million tons, or 79% of the 2.94 million tons. The bulk of the ore was screened at the individual mine sites and then shipped to the company's Doniambo metallurgical complex outside the capital of Nouméa (Eramet Group, 1998).

At Doniambo, the ores from the five mines were blended along with ores from a few independently operated mines, partially dried, calcined, and then smelted in one of three electric arc furnaces. The Doniambo smelter produces ferronickel containing 29% nickel and nickel matte that assays about 75% nickel. The matte is sent to the Sandouville-Le Havre refinery in northern France for conversion into cathode. (New Caledonia is an overseas territory of France.) The Sandouville refinery is owned by the Eramet Group, SLN's parent company. In 1997, the Doniambo smelter produced 44,312 tons of nickel in ferronickel and 10,580 tons of nickel in matte. The combined output of 54,892 tons was an alltime high for Doniambo, breaking the previous record of 53,412 tons set in 1996.

SLN accounted for 42% of New Caledonian mine production in 1996. The other 58% of mine production was divided between La Société Minière du Sud Pacifique (SMSP), J.C. Berton Mines, Nickel Mining Corp., Société des Mines de la Tontouta, and several other independent mining companies. In 1997, the overseas territory exported 79,578 tons of nickel in ore, which included 41,078 tons of nickel in garnerite shipped to Japan; 17,605 tons in garnerite shipped to the United States; and 20,895 tons in limonitic laterites shipped to Australia.

In 1996, SMSP and Falconbridge formed a partnership with the intention of building a ferronickel plant in the North Province. The plant would have an annual capacity of 54,000 tons of nickel in ferronickel and use local lateritic ores as feedstock (Falconbridge Limited, 1997a). The two companies then prepared a scoping study and presented it to the governments of France and the territory. The ferronickel project was being supported by the island's separatist party—Front National de Liberation Kanak et Socialiste (FNLKS), which is especially strong in the North Province. The Kanak Front was told that the mining and smelting complex would employ 700 islanders and lead to the indirect employment of an additional 2,000. However, to be economically viable, the project required a minimum of 25 years of ore reserves. These reserves exist, but many of the better deposits near the proposed plant site were already controlled by SLN, the principal mine operator on the island. There are three key deposits in the vicinity of the proposed plant: Tiébaghi, Poum, and Art. Together they have an estimated 1.6 million tons of nickel in garnierite reserves averaging 2.5% nickel.

Eramet was being pressured to surrender part of these key reserves, which were considered vital to the future viability of SLN (Eramet Group, 1997). Initially, SLN was asked to cede its new Tiébaghi Mine being developed at the northwestern tip of the island. Eramet countered with a proposal calling for SMSP to cut back on its ore exports and, instead, use part of its mine production as feed for the proposed plant. SLN and the island's other mine operators would make up any shortages in feedstocks. Supported by the Government of France, SMSP then proposed to swap its Poum Mine for SLN's Koniambo deposit. The Koniambo deposit is roughly midway between Kaala-Gomen and Népoui-Kopéto and has much larger reserves than Poum. In December 1996, Eramet's board of directors agreed in principle to the swap if adequate financial compensation were made to SLN, but negotiations stalled shortly afterwards.

At the beginning of 1997, the Government of France considered buying or, as a last resort, expropriating the Koniambo deposit and turning it over to SMSP and Falconbridge. Eramet had not planned to mine the deposit until 2010. The Government of France is the largest shareholder in Eramet, with an interest of 55%. The minority shareholders, which include several mutual funds and pension funds based in the United States and the United Kingdom, were strongly opposed to any type of expropriation.

The Kanak Front, the local trade unions, and the Government of France all would prefer to have more ore processed on the island and less exported. In October and November, the trade unions blockaded SLN's mining centers in support of the proposed ferronickel plant. The blockade caused SLN to lose 1,300 tons of production on a contained nickel basis. On November 3, a mediator appointed by the French Government negotiated a tentative accord between Eramet, Falconbridge, and SMSP, ending the blockade several days later. On February 1, 1998, SMSP signed a protocol with the French Government, the Eramet Group, and others, permitting the formal exchange of mining assets. Under the protocol, SMSP will gain access to SLN's Koniambo deposit. In exchange, SLN will receive mining rights to the smaller Poum deposit held by SMSP (Eramet, 1998; Falconbridge Limited, 1998b; Mining Journal, 1997c).

In September 1996, QNI Limited of Australia and Société des Mines de la Tontouta (SMT) signed an agreement to develop several limonitic nickel deposits on New Caledonia. The two partners have since formed a joint venture called Société des Mines de Bogota (SMB) to develop key properties on the island's Bogota Peninsula. QNI has a 67% interest in SMB through its subsidiary, QNI Nouvelle Caledonie S.A. However, the agreement still had to be approved by the French Government. Four mining companies on the island currently supply ore to QNI's Yabulu refinery near Townsville, Queensland—Nickel Mining Corporation, J.C. Berton Mines, SMT, and SMSP. The four companies accounted for 59% of QNI's ore supplies in fiscal year 1996-97 (QNI Limited, 1998a). The remaining ore came from P.T. Aneka Tambang's mine on Gebe Island in Indonesia (35%) and Hintuan Mining Corporation's operations in the

Philippines (6%). In late 1997, SLN also linked up with QNI. The two were considering building an ore processing plant in the North Province.

In September 1997, Inco Limited's management gave the go-ahead to construct a $50 million pilot plant near the Goro laterite deposit at the southeastern tip of the island (Inco Limited, 1997b). The main Goro deposit reportedly has 165 million tons (on a dry weight basis) of drill-indicated resources averaging 1.60% nickel and 0.16% cobalt (Inco Limited, 1998b). Drilling has already outlined 47 million tons of proven reserves—enough to supply a commercial-size plant for 20 years. The project—Goro S.A.—is a joint venture of Inco (85%) and the French Government agency Bureau de Recherches Géologiques et Minières (15%).

A detailed feasibility study of the Goro deposit was begun in July 1995 and completed in March 1997. The results of the Goro study were presented to the New Caledonian territorial government and public shortly afterwards. A project team has been assembled to carry out critical engineering work. When the integrated pilot plant is completed in 1999, it will be able to process 12 tons of ore per day using new proprietary technologies developed by Inco. The pilot plant will be a hydrometallurgical operation utilizing acid pressure leaching and solvent extraction. Inco is considering building a full-scale commercial plant on-site if the pilot plant is a success. The proposed commercial plant would have an initial annual capacity of 27,000 tons of nickel and 2,700 tons of cobalt. Because the proposed Goro Mine would be an open pit operation and generate byproduct cobalt, it has the potential of being one of the more economical nickel producers in the world.

***Norway***.—Falconbridge Nikkelverk A/S produced 62,702 tons of refined nickel, up slightly from 61,584 tons in 1996 (Falconbridge Limited, 1998). Shipments of matte from Falconbridge's smelter at Sudbury and BCL Ltd.'s smelter at Selebi Phikwe in Botswana—the two principal sources of nickel—were down 11% and 13%, respectively, from 1996 levels. However, the decreases were largely offset by increased imports of matte from Australia and South Africa. The Nikkelverk refinery at Kristiansand was expanded in 1994 and again in 1997—this time to accommodate matte made at Sudbury from Raglan concentrates. The complex is now capable of producing 85,000 tons per year of refined nickel metal and 3,700 tons of refined cobalt. In 1995 and 1996, the Nikkelverk operation suffered from a shortage of matte. This problem should disappear now that the Raglan Mine is in full production.

In December 1995, Outokumpu Base Metals Oy acquired a 70% interest in Nikkel og Olivin A/S. The remaining 30% was held by Nordlandsbanken AS, a Norwegian Bank. Nikkel og Olivin mines nickel sulfide ores at Ballangen, about 30 kilometers southwest of the iron ore port of Narvik in Nordland. In 1997, the entire annual output of the underground mine—some 2,500 tons of nickel in concentrate—went to the Harjavalta smelter in Finland.

***Papua-New Guinea***.—In April 1997, Placer Dome Inc. sold its 65% interest in the Ramu nickel-cobalt project to a newly formed company—Highlands Pacific Limited. The sale was part of a divestiture of non-gold interests acquired by Placer Dome when it took over Highlands Gold Limited earlier in the year. On June 12, Highlands Pacific was formally listed on the Australian Stock Exchange and successfully raised A$210 million in its initial public offering. Nord Pacific Limited, an Australian-based copper producer and exploration company, holds the remaining 35% equity. Nord Pacific has been a partner in the Ramu joint venture since 1978, when the venture was formed. The Government of Papua Guinea can acquire up to a 30% interest in the venture at any time prior to commissioning of the mine, but must contribute exploration and development funds commensurate with its equity holdings (Mining Journal, 1997e).

The Ramu laterite deposit is about 35 kilometers inland from the northern coast of New Guinea, at a point about 80 kilometers southwest of the port of Madang. The exploration license, giving access to 244 square kilometers of land in the Marum Basic Belt, was originally granted in 1972 and was renewed in February 1996. The principal bedrock is serpentinized dunite, which has weathered up to 50 meters thick in some places. Significant peridotite and pyroxenite are also present. The laterite, which is more typically 25 to 30 meters thick, also contains disseminated chromite that has resisted weathering more than the other bedrock minerals. According to Highland Pacific officials, the Ramu deposit has 33 million tons of measured resources, averaging 0.91% nickel and 0.10% cobalt, plus 19 million tons of indicated resources, averaging 1.20% nickel and 0.09% cobalt (Highlands Pacific Limited, 1998).

A feasibility study was begun in June 1997 and was to be completed by October 1998. The surrounding area contains an additional 80 to 92 million tons of inferred resources of about the same grade. The overall waste-to-ore stripping ratio is very low, about 0.2 to 1. The ore would be screened on-site, and gravity separators would be used to remove the coarser grains of abrasive chromite. After screening, the slurried ore would be pumped through a 78-kilometer-long pipeline to a hydrometallurgical extraction plant on the coast at Erima, or possibly Astrolabe Bay. The proposed plant would use pressurized acid leaching followed by solvent extraction and electrowinning to produce 23,000 tons per year of nickel metal and 2,800 tons per year of cobalt salts (Worthington, 1997). The study was being conducted by Fluor Daniel and H.A. Simons.

***Russia***.—The Russian Federation produced 230,000 tons of nickel in refined products, about 21% more than in 1996. RAO Norilsk Nickel was by far the largest producer, accounting for 218,000 tons of nickel in metal or limited amounts of ferronickel, along with 370,000 tons of copper metal, and 4,330 tons of cobalt in metal, oxide, or sulfate. Norilsk Nickel produced 23% more nickel than in 1996, when the company had a reported output of 177,185 tons (Interfax International Limited, 1998; Platt's Metals Week, 1997c). Part of the production increase was attributed to improved flotation separation techniques at the company's largest operation—the A.P. Zavenyagin Norilsk Nickel Mining and Metallurgical Combine on the Taimyr Peninsula. The introduction of a new flotation reagent has dramatically increased concentrate recovery. In December, an amendment was made to Russia's law on state security that prohibits the company from releasing detailed production figures for its different subsidiaries (Metal Bulletin, 1998b).

Two subsidiaries manage Norilsk's assets on the Kola Peninsula. A/O GMK Pechenganikel is responsible for the mines, concentrator and roaster at Zapolyarny as well as the mine and copper-nickel smelter at Nikel. A/O GMK Severonikel manages the copper-nickel-cobalt smelting and refining complex at Monchegorsk. The Severonickel Combine made a major comeback in 1997, increasing nickel production by 55%. One proposal under evaluation called for the ore smelting furnace at Monchegorsk to be converted from the production of copper-nickel matte to ferrochromium. The chromite ore could come from the Sopcheozerskoye deposit also located on the Kola Peninsula. An alternative proposal called for the smelter to be closed, but the refinery to be expanded. Norilsk Nickel reportedly was prepared to pay part of Severonickel's overdue tax debts rather than let the subsidiary go bankrupt (Metal Bulletin, 1998b). The Federation's emergency commission on tax collection ordered Severonickel to pay 249 million rubles (about $40 million) in back taxes by August 1, 1998, or risk seizure of its assets. Norilsk Nickel was discussing the formation of a strategic partnership with Falconbridge Limited, Outokumpu Oyj, and Sumitomo Metal Mining Co. Ltd. (Platt's Metals Week, 1998b). The new partner, or partners, would help Norilsk Nickel upgrade the Severonickel complex and introduce new hydrometallurgical technology to help lower production costs. An array of technological improvements were already underway at both Pechenganickel and at the main operations of the Norilsk Combine in Siberia. Pechenganickel has rebuilt or repaired much of the gas cleaning systems at its roasting and smelting complexes. The water purification system at Pechenga also has been overhauled. All of these improvements should help raise metal recoveries, lower production costs, and reduce environmental pollution in the near future.

The production increases came at a time when Norilsk Nickel was undergoing a change in management and struggling with inflation. The company had difficulty meeting its payroll and purchasing essential supplies because of the ongoing decline in world nickel prices and sharp increases in fuel, energy, and labor costs at home triggered by inflation. A 48% increase in export sales of nickel metal by the Norilsk Combine was partially offset by a dramatic drop in domestic sales by the entire company. Only about 22,000 tons—10% of Norilsk Nickel's 1997 output—went to Russian consumers. The drop in company domestic sales reflected not only a collapse in Russian consumption of nickel but also an end to the company's practice of making barter transactions. Many of the barter transactions resulted in the exporting of cathode and other company products by intermediaries (Interfax International Ltd., 1998; Pirani, 1998). All sales are now centralized and handled by the Interrosimpex trading company.

Plans were underway to develop the Pelyatkinskoye natural gas field in north-central Siberia. Construction of a pipeline to the smelting and refining complex at Norilsk would cost an estimated $360 million. In 1996, the Norilsk Combine had difficulty maintaining production because of cutbacks in deliveries of natural gas. The combine's sole supplier, NorilskGazProm, had threatened to reduce deliveries by 25% if Norilsk did not pay $173 million owed the utility (Metal Bulletin, 1997a,b). NorilskGazProm has a monopoly on natural gas in the Taimyr region, but has been rapidly depleting its reserves, forcing the utility to raise prices. The Norilsk Combine is the utility's biggest customer. Development of the Pelyatkinskoe gasfield would help alleviate the depletion problem, but NorilskGazProm lacked the massive financial resources required for such a project.

In the fall of 1997, NorilskGazProm and several smaller creditors of the Norilsk Combine asked the bankruptcy court in Krasnoyarsk to declare the combine insolvent (Metal Bulletin, 1997a). In October, Norilsk Nickel won three seats on the board of directors of NorilskGazProm after buying an estimated 30% interest in the utility. Norilsk Nickel's management hoped that the new board would agree to a restructuring of the Norilsk Combine's gas debt, neutralizing the utility's bankruptcy motion against the combine (Metal Bulletin, 1997b).

Norilsk Nickel was partially privatized in April 1994 and has had its management reorganized several times in the past 3 years. The Russian government was the principal shareholder in the joint-stock company prior to 1995. In November 1995, United Export-Import Bank Open Joint Stock Company (UNEXIM Bank) acquired 51% of Norilsk Nickel's voting stock from the Government under a controversial loans-for-shares program (Mining Journal, 1997a). The Government gave the stock to UNEXIM Bank as collateral in exchange for a $170 million loan. The stock transfer was later approved by the Duma—the Russian parliament—effectively giving UNEXIM Bank a 38% interest in the company and control of the giant nickel producer. UNEXIM Bank is one of the larger commercial banks in Russia and is based in Moscow. The bank was set up in 1993 to expedite foreign trade transactions following the collapse of the Soviet Union.

In mid-1997, UNEXIM Bank took steps to gain official ownership rights to Norilsk Nickel. When the Government failed to pay back the bank loan on July 1, the Government lost ownership of its 38% controlling interest. On August 5, the block of stock was sold at a special auction closed to foreign investors. The auction was marked by confusion, controversy, and questions about its legality. The Government still considers Norilsk Nickel to be a strategic state asset and tried to halt the auction at the last minute (Interfax America, Inc., 1997). ZAO SVIFT, a company affiliated with UNEXIM Bank, won the tender with its bid of Ecu 236.2 million (about $250 million). SVIFT also agreed to retire some $70 million in tax and pension obligations and invest $300 million in the development of the Pelyatkinskoye gasfield (Mining Journal, 1997a).

In December, Outokumpu formed a joint venture with Norilsk Nickel to evaluate a number of mines and resources currently controlled by Norilsk in the Pechenga area. The new venture—A/O Polar Mining—began an 18-month study to determine if it would be profitable for Outokumpu and Norilsk to jointly upgrade some of Norilsk's existing mining and concentrating operations on the Kola Peninsula. A/O Polar Mining also was exploring the possibility of developing new mines in the Pechenga and Monchegorsk regions. The feasibility study was focusing on ways of lowering mining and mineral dressing costs while simultaneously meeting the most stringent environmental standards accepted by the international community. Alternative sources of financing were also to be investigated.

Fourteen copper-nickel deposits have been discovered in the Pechenga-Allarechenskiy region, giving Pechenganickel a minimum of 60 years of reserves (Blatov and Sokolov, 1996). The Kaula deposit, one of several resources identified during the

1930's and 1940's, was the first to be mined. In 1947, the largest of the 14 deposits was discovered—the Zhdanovskiy. Development of the Zhdanovskiy deposit took place between 1951 and 1965, increasing reserves in the region six-fold. Two medium-sized deposits—Kotselvaara-Kammikivi and Semiletka—were also developed during the 1960's. Other key deposits (with their years of discovery shown in parentheses) include: Bystrinskiy (1978-86), Sputnik (1973-77), Tundrovoy (1985-90), and Zapolyarny (1968). Bystrinskiy, Sputnik, and Tundrovoy are all being held in reserve. Four mines are currently in production—the Central and Western open pits in the upper part of the Zhdanovskiy deposit, the neighboring Northern underground operation in the Zapolyarny deposit, and the Kaula-Kotselvaara underground operation in the Kotselvaara-Kammikivi and Semiletka deposits. The ores of the Nittis-Kumuzhye deposit and related reserves in the Monchegorsk region were depleted during the 1960's and 1970's.

Outokumpu Technology was recently involved in the modernization of the Zapolyarny concentrator. Outokumpu is also helping the Norilsk Combine reline and upgrade one of two Outokumpu-designed flash furnaces at the Nadezdhinskiy smelter on the Taimyr peninsula.

Russia has three smaller producers, all in the Ural Mountains—RAO Ufaley Nickel, RAO Yuzural Nickel, and RAO Režsky Nickel. The Ural producers continued to be hampered by escalating prices for energy, especially coal, and a shortage of capital for modernization.

According to statistics compiled by the central government, Russia exported 218,700 tons of unwrought nickel (HTS No. 7502.10) in 1997. Of the 218,700 tons, 208,200 tons, or about 95%, went into LME warehouses in Rotterdam. The only other significant destination was Finland, which accounted for 8,700 tons, or 4%. Direct shipments to Germany and the Republic of Korea were down dramatically from 1996 levels. Norilsk Nickel shipped only 449 tons of matte (on a gross weight basis) to Falconbridge's Nikkelverk refinery in Norway. The Nikkelverk refinery processed a total of 103,000 tons of Russian matte between 1988 and 1994. However, no shipments were made in 1995 or 1996.

In the last few years, Russia has become an important source of nickel-bearing stainless steel scrap. In 1997, approximately 346,000 tons of scrap (on a gross weight basis) went to the EU. Most of the scrap came from obsolete military and industrial equipment. Several foreign stainless steel producers and scrap trading firms have set up collection operations in Russia and Ukraine.

***Venezuela***.—In July, the Venezuelan Ministry of Mines and Energy formally awarded the Loma de Níquel concession to Minorco S.A. of Luxembourg, permitting excavation of the long-planned open pit mine to begin. The Loma de Níquel deposit was identified in 1941 and evaluated by SLN and several other companies before Minorco took over the project in 1996. The concession will run for 30 years. Loma de Níquel (formerly Loma de Hierro) is about 85 kilometers southwest of Caracas in the States of Miranda and Aragua. The nickeliferous laterite deposit is conveniently situated between a major gas pipeline and a high-voltage transmission line. The $450 million mine and smelting complex will employ 600 workers and indirectly create an additional 3,750 jobs in the surrounding communities. Ferronickel would be produced on-site and trucked 200 kilometers to Puerto Cabello for export to stainless steel meltshops. The project was being managed by Minera Loma de Níquel C.A., a majority-owned subsidiary of Minorco.

Financing was being provided by Germany's Kreditanstalt für Wiederaufbau ($100 million), the World Bank's International Finance Corporation (IFC) ($65 million), and an IFC syndicate headed by Luxembourg's Dresdner Bank ($50 million) (Burgert, 1997). The remaining $235 million would be raised by the project shareholders—Anglo-American Corp. of South America Ltd. (AMSA) (81.5% equity), Jordex Resources Inc. (7.5%), and Corporación Caracas (7.5%). The IFC has a 3.5% interest in the project. AMSA is a subsidiary of Minorco.

The Loma de Níquel deposit has 34 million tons of reserves grading 1.48% nickel and an additional 6 million tons of resources, also grading 1.48% nickel (Platt's Metals Week, 1997b). The smelter would have an annual production capacity of about 16,000 tons of nickel in ferronickel and could be in production by mid-2000. Construction of infrastructure began in the first quarter of 1998.

***Zimbabwe***.—In December, the Government of Zimbabwe acquired 23.4 million shares of stock in Bindura Nickel Corporation Limited (BNC). The shares were purchased from Anglo American Corporation Zimbabwe Limited, BNC's principal shareholder, for Z$6.25 per share—some US$12 million—and gave the Government a 20% interest in the nickel producer.

BNC milled 3.06 million tons of ore in 1997, about 2% less than in 1996, and produced 11,000 tons of nickel in concentrates (Bindura Nickel Corporation Limited, 1998). The concentrates came from four underground mines—the Trojan (4,620 tons of contained nickel), the Shangani (3,270 tons), the Madziwa (1,740 tons), and the Epoch (1,340 tons). Mill head grades ranged from a low of 0.44% for the Shangani to a high of 0.61% nickel for the Trojan. The company has delineated 45.5 million tons of resources averaging 0.60% nickel, sufficient tonnage to keep the mines operating for at least 15 years. Included in this figure are 427,000 tons of broken ore grading 0.55% nickel and proven reserves of 4.93 million tons grading 0.52% nickel. Probable reserves consisted of 2.18 million tons grading 0.54% nickel.

BNC was considering importing nickel concentrates from Australia and South Africa to better utilize its smelting and refining complex. In 1997, the complex produced 12,963 tons of nickel cathode, 1,933 tons of copper, and 132 tons of cobalt (in cake). Of the 12,963 tons of cathode, 9,923 tons came from BNC operations and 3,039 tons from toll work. The complex has a design capacity of 15,000 tons per year of nickel cathode. In recent years, the Japanese plating industry has been a significant buyer of Zimbabwean nickel.

In October, the Hartley Mine made its first shipment of platinum-group metals. The new mine cost US$264 million and was expected to be in full production by yearend 1998, extracting ore at a rate of 2.2 million tons per year. Nickel would be recovered as a byproduct and refined on-site at a rate of 3,200 tons per year. Difficult ground conditions have hindered mine development and put the project a year behind schedule (Platt's Metals Week, 1998c). A shortage of experienced miners compounded the delay. The Hartley Mine is a joint venture of Broken Hill Proprietary Company Limited (67% interest) and Delta Gold NL (33%)—both of Australia.

## Current Research and Technology

***Nickel-Based Batteries for Electric Vehicles***.—AEG AG, Anglo American Corporation, BMW AG, and Daimler-Benz AG have teamed up to manufacture an advanced sodium metal-nickel battery called the ZEBRA. The technology was originally developed in South Africa, the overall charging reaction being: $Ni^o + 2\ NaCl \rightarrow 2\ Na^o + NiCl_2$. When the cell discharges, the reaction is reversed, generating a cell voltage of 2.58 volts at a temperature of 300° C. By connecting multiple cells in series, much higher voltages can be attained. The ZEBRA battery combines key advantages of the molten sodium metal battery with those of the nickel metal-hydride battery. The molten sodium battery was promoted in recent years by Silent Power Co. Ltd. of the United Kingdom and the Ford Motor Co. However, Ford uncovered a number of engineering problems with the molten sodium battery during road testing and has shelved its development project for the near term.

The ZEBRA battery uses a mixture of salt (NaCl) and nickel metal for the positive electrode and has a solid electrolyte (Dustmann, 1998). The salt and nickel mixture is packed inside a vertical ceramic tube. The tube, in turn, is encapsulated within a steel can. The ceramic tube serves as the primary electrolyte and also keeps the positive electrode (i.e., the salt mix) from directly contacting the steel can. The can serves as the cell casing and the negative pole of the cell. During charging, the sodium chloride decomposes to form sodium ions and chloride ions. The sodium ions are much smaller than the chloride ions and pass through the wall of the ceramic tube, which is composed of pure beta-$Al_2O_3$. The sodium ions form liquid sodium metal when they reach the steel. To ensure contact between the solid positive electrode and the ceramic electrolyte, the positive electrode is flooded with a secondary molten salt electrolyte consisting of an equimolar, eutectic mixture of NaCl and $AlCl_3$, (i.e., $NaAlCl_4$). If the vehicle were in an accident that ruptured the battery, the molten sodium metal would react instantaneously with the secondary electrolyte to form salt and aluminum metal: $3\ Na^o + NaAlCl_4 \rightarrow 4\ NaCl + Al^o$.

This second-generation EV battery overcomes the range limitations of the lead-acid batteries currently powering some vehicles. The ZEBRA battery has a relatively high energy density of about 100-watt-hours per kilogram and reportedly meets many of the midterm goals established by the United States Advanced Battery Consortium (USABC). The battery can be put on fast charge and, in 50 minutes, have half of its discharge replaced (AEG ZEBRA Battery Marketing GmbH., 1997). Because the individual cells are designed to operate in a temperature range of 270° to 350° C, each battery pack has its own built-in heating and cooling system. AEG Anglo Batteries GmbH. was producing about 200 battery packs per year at its automated pilot-production line in Ulm, Germany, for trial use in vehicle fleets. Full-scale production was scheduled to start in 2001 at the rate of 30,000 packs per year. The ZEBRA battery also may be able to be scaled up in size and have industrial applications as a large energy storage unit.

French automobile manufacturers have been mass producing EV's since 1995. SAFT S.A. is currently producing about 5,000 EV battery modules per year for the industry at its new plant in Bordeaux. The $20 million plant is the first fully automated battery production facility in the world dedicated to the EV market. The capacity of the facility can be easily increased to 15,000 modules per year if demand develops. The plant manufactures low-maintenance nickel-cadmium batteries for a variety of EV's, including compact cars, minivans, shuttles, commuter vehicles, and scooters. SAFT's nickel-cadmium battery was available in three different sizes—all of which had a nominal voltage of 6 volts, but ranged in weight from 12.5 to 17.0 kilograms. The company also offered two nickel-metal hydride EV battery modules. The nickel-metal hydride modules had a higher energy density than their nickel-cadmium counterparts and extended the range of the vehicle by 25% (on an identical weight basis). The 12-volt liquid-cooled module weighed 18.8 kilograms, while its 24-volt counterpart weighed 37.3 kilograms. According to SAFT, an EV weighing 1,300 kilograms and powered by 12 of the 24-volt modules (for a total voltage of 288 volts) would have a range of more than 200 kilometers (124 miles). SAFT also had a 200-kilowatt-hour lithium-ion battery under development for EVs. The lithium-ion battery had a plastified carbon anode and a plastified nickel oxide cathode (SAFT Electric Vehicle Division, 1997).

Two electric vehicles powered by nickel-metal hydride batteries made their U.S. debut in calendar year 1997. In May, Honda Motor Co. Limited began offering its EV Plus to fleet owners in California. The four-passenger car was the first mass marketed EV in the United States to use advanced nickel-metal hydride batteries. The car was powered by 24 sealed battery modules connected in series. Each battery module had a nominal open-circuit potential of 12 volts. This configuration provided a total voltage of 288 volts to a DC brushless motor. The high-efficiency motor used high strength permanent magnets made from rare earths and had an output of 49 kilowatts. The body was designed exclusively as an electric car (Gale, ed., 1996). The EV Plus had a maximum speed of 130 kilometers per hour (about 80 miles per hour) and an approximate range of 210 kilometers (130 miles) in normal traffic. The official EPA City and Highway ranges were 100 miles and 84 miles, respectively, based on an 80% depth of discharge. Honda expected to market about 300 of the vehicles over the next year or two (Electric Vehicle Association of the Americas, 1997, Honda EV Plus vehicle specifications, 2 p., accessed October 22, 1997, at URL http://www.evaa.org/ vehicles/ honda.html).

In mid-October, Toyota Motor Sales USA, Inc. began offering its RAV4-EV sports utility vehicle to U.S. fleet operators. Like the EV Plus, the Toyota vehicle had 24 sealed nickel-metal hydride battery modules connected in series, providing 288 volts to an electric motor. The five-passenger RAV4-EV can travel about 210 kilometers on a single recharge—the same range as the EV Plus. The RAV4-EV can be recharged in about 8 hours using a 220-volt electric line—the same type of line already built into many U.S. homes to operate electric clothes dryers (Electric Vehicle Association of the Americas, 1997, Toyota RAV4-EV vehicle specifications, 2 p., accessed October 22, 1997, at URL http://www.evaa.org/vehicles/toyota.html).

In December, Toyota Motor Corporation began selling its new hybrid-powered Prius sedan in Japan and was planning to introduce the vehicle in the United States in late 2000. The hybrid vehicle has both a gasoline engine and an electric motor for propulsion. In low-speed, stop-and-go city driving, only the electric motor powers the car—drawing current from a nickel-metal hydride battery pack. At higher speeds, the power system switches automatically to the gasoline engine. When the engine is running, part of the crankshaft's mechanical energy is transferred to a generator which recharges the battery pack. Toyota has been producing between 2,000 and 3,000 hybrid vehicles per month at its plants in Japan (Koyama, 1998). The Prius costs about $4,300 more than Toyota's standard car, but prices are expected to come down as production increases. The hybrid system reportedly has almost twice the fuel efficiency of a conventional gasoline engine as well as significantly reduced exhaust emissions (The Times @ Toyota, 1997, Toyota reveals futuristic cars: Toyota Motor Sales USA Inc., 1 p., accessed October 23,1997, at URL http://www. toyota.com/times/).

On November 12, General Motors Corporation delivered its first Chevrolet S-10 pickup truck equipped with an advanced nickel-metal hydride battery to Southern California Edison Co. for evaluation. Identical trucks were delivered to Detroit Edison Co. and Georgia Power Co. the next day. The three trucks were the first of 30 to be field tested under a set of partnerships between General Motors' Advanced Technology Vehicles group and regional utilities that had been most supportive of the emerging EV industry (Energy Conversion Devices, Inc., 1997). The nickel-metal hydride battery packs were made by GM Ovonic L.L.C., a joint-manufacturing venture set up in 1994 by Ovonic Battery, Inc. and General Motors. Ovonic Battery is a subsidiary of Energy Conversion Devices, Inc. of Troy, MI. The batteries provide more than twice the driving range of lead-acid batteries of the same weight. The new battery pack weighed 430 kilograms (950 pounds). Data gathered during the field tests were used to improve the GM Ovonic battery before it was put into full production for the S-10 truck in the first half of 1998. The field test was just one of a number of ongoing developments designed to put thousands of EV's on U.S. highways in an effort to curb urban air pollution (Wilkinson, 1997). U.S. and Japanese automobile manufacturers have agreed to comply with clean air requirements mandated by California and other States beginning in the year 2003. General Motors was planning to use a similar GM Ovonic battery to extend the range of its EV-1 passenger car to 260 kilometers (160 miles). The company began leasing a lead-acid powered version of the EV-1 in December 1996 and expected to begin limited production of an improved, nickel-metal hydride powered model by yearend 1998.

Nissan Motor Co. Ltd. was planning to provide a demonstration fleet of 30 Altra EV's to a select number of U.S. fleet users in 1998. An additional 90 vehicles were to be manufactured and delivered in 1999 (Bagot, 1997). The Altra is a cross between a minivan and a sports utility vehicle. Power comes from a lithium-ion battery pack developed jointly by Nissan and the Sony Corp. The battery pack weighs 360 kilograms (800 pounds) and contains 12 modules or 96 lithium-ion cells. Lithium-ion batteries have about 1.5 times the energy density (i.e., storage capacity) of equivalent nickel-metal hydride batteries.

***Magnetic Superconductors Made From Rare-Earth–Nickel Borocarbides***.—Since the discovery of superconductivity in 1911, solid-state physicists have identified some 2,000 alloys and compounds that exhibit the phenomenon. When a conductor made from one of these materials is cooled below its superconducting transition temperature, $T_c$, the electrical resistance of the conductor drops to zero. This critical temperature varies from material to material, but is normally within 25 degrees of absolute zero (-273.15° C). Only a few of the 2,000 materials have high enough transition temperatures to be of any practical importance. Superconductors have a number of practical applications, most of which are still in the early stages of development—for example, high intensity magnets; superconducting electrical transmission lines, motors, and generators; and levitated trains and subway cars.

Superconducting behavior is destroyed when a sufficiently intense magnetic field is applied to the conducting material. Below this critical field, magnetic flux is excluded from the superconductor. Magnetic impurities strongly suppress superconductivity in pure elements and binary compounds. This last observation encouraged researchers to investigate conductors made from rare-earth compounds. In the late 1970's, two families of superconducting rare-earth compounds were found to have unusual magnetic properties—$RMo_6S_8$ and $RRh_4B_4$ (where R represents a rare-earth element). In 1994, a new family of magnetic superconductors was discovered—the $RNi_2B_2C$ series. Since then, superconducting compounds belonging to the nickel-based borocarbide series have been made from yttrium and 6 of the 14 lanthanides (Canfield, Gammel, and Bishop, 1998). Most of the rare earths used have been the heavier members of the lanthanide family (i.e., dysprosium through lutetium). Single $RNi_2B_2C$ crystals weighing up to 0.8 grams have been grown from molten nickel boride ($Ni_2B$). Carbon is apparently an essential component of these superconducting compounds. Crystallographic studies show that the structure of the single crystal consists of a sandwich of rare-earth–carbon sheets separated by slabs of $Ni_2B_2$. Future research on these nickel-based compounds is expected to greatly expand human understanding of the relationship between magnetism and conductivity.

## Outlook

Since late 1997, economic crises in East Asia and Russia have depressed the world price of nickel. The ongoing financial turmoil in the world, the cutbacks in consumer purchases, and the postponement of some major construction projects caused stainless steel production to level off. Nickel prices are currently at their lowest level since 1986. The long-term outlook for nickel consumption, though, has not changed.

Demand for austenitic stainless steel will continue to drive the world nickel market for at least another 20 years. World consumption of all types of stainless steel in 1998 is expected to be slightly less than the 1997 preliminary estimate of 13.5 million tons. However, beginning in 1999, stainless steel consumption is expected to grow between 2% and 5% annually until the year 2005. After 2005, the growth rate could rise even more, perhaps reaching 9%, if the Russian economy turns around. Rejuvenation of Russian industry would require large amounts of stainless sheet and plate to support a technologically advanced, market-oriented society.

Surprisingly, there also is potential for increased consumption of stainless steel in the United States. Per capita consumption of stainless steel in the United States is less than one-half of that in countries like Italy, Japan, the Republic of Korea, and Taiwan (Inco Limited, 1997a). U.S. industry is finding that it is cost-effective to fabricate machinery, plumbing fixtures, and critical parts for industrial equipment from stainless steel, or even superalloys, despite the higher cost of these materials. The higher initial cost of using more durable, nickel-containing steels and alloys is justified when compared to the alternative of high-labor costs, customer ill will, and downtime incurred when less expensive materials fail.

Several forces are helping to sustain long-term growth in nickel consumption. First, faster transport, the explosive expansion of telecommunications systems, and the globalization of markets are forcing local communities to be more technologically astute. As a result, society is becoming increasingly dependent on products fabricated from sophisticated materials—many of which contain significant quantities of nickel. Second, a technologically advancing society is continually demanding new materials with improved resistance to corrosion and heat—again favoring nickel. Recent life cycle studies have shown that horrendous bills for repairing highway bridges and similar infrastructures could have been avoided by substituting more expensive, but corrosion-resistant, stainless for traditional carbon steel in the original design (Whiteway, 1998). Third, the cost of producing a ton of stainless steel has fallen because of technological advances and improved economies of scale, making stainless more price competitive. Fourth, the population of the world is growing, increasing demand for quality stainless kitchenware, food processing equipment, sinks, and plumbing parts.

In late 1997, Japanese stainless steel producers began to experience a significant drop in sales because of Japan's worsening economic situation and the currency crises in Indonesia and other Southeast Asian countries—important consumers of Japanese steel. Japan is the largest nickel consuming country in the world. The Japanese steel industry alone consumed 137,000 tons of primary nickel in 1997. Recent currency devaluations in the Republic of Korea and Taiwan have made their stainless products more competitive with those of Japan. Cutbacks in stainless steel consumption in Japan are being offset by increased demand in the EU. Demand for austenitic stainless steel has resumed in several EU member countries whose economies were weakened by the global recession of 1991-93. In addition, production of stainless steel is being expanded in some of the newer industrialized countries, like South Africa.

The warming of relations between Russia and the United States, together with the peaceful expansion of the EU, is having a tremendous effect on the nickel market. Russia is now a major source of nickel for the United States. Almost all of the 33,000 tons of nickel metal that was once held in the National Defense Stockpile has been sold, making the United States more vulnerable to offshore supply disruptions and partially reliant on Russian mines until the Voisey's Bay deposit is developed.

Demand for nickel-bearing superalloys is expected to grow despite recent restructuring of the aerospace market and the ongoing economic problems in East Asia and Latin America. The aerospace market has gradually been shifting from a government-dominated market to one that is more evenly balanced between commercial and government purchases. The effects of restructuring the North American and European aerospace industries also has affected some of their raw material suppliers. Declining orders for aerospace-grade metals and alloys from a downsized United States-Canadian defense industry has forced several superalloy suppliers to restructure and seek out new markets. The acquisition of Teledyne by Allegheny Ludlum in 1996 was the first step in restructuring the entire North American superalloys and specialty steel sector. U.S. specialty steel producers have been feeling pressure from their European competitors for some time. The second step will be the assimilation of Inco Alloys International (IAI) by Special Metals Corporation. Special Metals successfully bid for IAI, a much larger operation, in July 1998 after the proposed acquisition of IAI by Haynes ran into opposition from antitrust regulators.

Automotive manufacturers are under intense pressure to reduce exhaust emissions from automobiles and other vehicles powered by internal combustion engines. Toyota's Prius and other hybrid vehicles offer one solution, while EV's offer another. EV's are now being manufactured by the hundreds at assembly plants in the EU, Japan, and the United States. So far, most of the hybrid vehicle production has been restricted to Japan. Around the world, automobile manufacturers, metal producers, electric utility managers, environmentalists, and regulatory officials are watching to see how the first mass-produced EV's will be received by the general public. Five different battery chemistries are being used: nickel-cadmium, nickel-metal hydride, valve-regulated lead-acid (VRLA), lithium-ion, and zinc-air. The sodium metal-nickel battery is also close to mass production. Should one of the nickel battery chemistries become the industry standard, demand for nickel will increase and may necessitate changes in nickel mining and smelting technology.

The market for nickel-based batteries is expected to grow at least 6% per year over the next 10 years, even if American automobile manufacturers decide to substitute lithium-ion cells for nickel-metal hydride cells in their third-generation EV's or first-generation hybrid vehicles. Nickel-cadmium and nickel-metal hydride batteries are strong contenders for the rapidly growing electric scooter/bicycle market in the developing countries and they will continue to be used as an internal energy source in rechargeable power tools, home appliances, and other household items because of cost constraints. Government officials in the EU are currently weighing the pros and cons of banning cadmium, but are finding that the proposed legislated phaseout of nickel-cadmium batteries may be too simplistic and create worse environmental risks.

Several petroleum geologists have published articles in the past 2 years predicting that world supplies of petroleum will tighten significantly sometime between 2010 and 2045 (Youngquist, 1998). These predictions are based on a number of observations. First, per capita use of petroleum in the United States has declined only 11% since the 1973 oil embargo, but oil imports have risen to record levels (U.S. Energy Information Administration, 1998). Crude oil production in the lower 48 States peaked in 1970. U.S.

dependence on foreign oil has risen from 28% in 1972 to 48% in 1997 despite new oilfield discoveries in Alaska and the Gulf of Mexico and despite the development of new and highly successful exploration technologies. U.S. per capita use of petroleum has declined only marginally over the past 25 years despite major improvements in home-heating practices, automobile engine efficiency, etc. and despite the massive shutdown or conversion of oil-fired power stations. Second, crude oil production in all of North America peaked about 1984—and in the former Soviet Union, about 1987. Third, oilfield discoveries worldwide peaked in the early 1960's and have been falling steadily ever since (Campbell and Laherrère, 1998). Campbell and Laherrère estimate that about 80% of the oil produced today flows from fields discovered before 1973. At the same time, the world will likely double its energy use by 2030, and quadruple its use by 2100 (Richardson, 1998). Much of the growing demand for energy will occur in China and other heavily populated countries that are undergoing rapid development.

Nickel consumption patterns could change dramatically after 2010 if these predictions of tightening oil supplies come true. Nickel consumption could significantly increase because EV's would become a more economically viable alternative to automobiles powered by internal combustion engines. The market for large energy storage devices for nationwide telecommunications systems and for emergency power supplies would also grow, further encouraging the scale-up of both nickel-metal hydride and sodium metal-nickel batteries.

The nickel supply system would also be affected. The remaining ferronickel production facilities that rely on electric power from oil-fired power stations would be put at a distinct disadvantage. The P.T. Inco operation in Indonesia and other mining-metallurgical complexes that rely on hydroelectric power would become more competitive. As in 1979, higher oil prices would encourage developers of new mines to turn more to hydrometallurgical processes, such as those proposed for Goro and Pinares de Mayari West.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT NICKEL STATISTICS 1/

(Metric tons of contained nickel unless otherwise specified)

| | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|
| United States: | | | | | |
| Mine production | 2,460 | -- | 1,560 | 1,330 | -- |
| Plant production | 4,880 | -- | 8,290 | 15,100 | 16,000 |
| Secondary recovery from purchased scrap: | | | | | |
| From ferrous scrap | 46,600 | 48,900 | 54,400 | 48,800 | 58,600 |
| From nonferrous scrap | 7,460 | 9,690 | 10,200 | 10,500 r/ | 10,200 |
| Exports: | | | | | |
| Primary | 7,180 | 7,420 | 9,750 | 13,100 | 16,400 |
| Secondary | 26,000 | 34,500 | 41,800 | 33,600 | 40,200 |
| Imports for consumption: | | | | | |
| Ore | 2,970 | -- | 8,200 | 15,000 | 17,600 p/ |
| Primary | 126,000 | 127,000 | 149,000 | 142,000 | 147,000 |
| Secondary | 6,710 | 6,070 | 7,930 | 8,060 | 11,000 |
| Consumption: | | | | | |
| Reported: | | | | | |
| Primary | 105,000 | 107,000 r/ | 125,000 r/ | 119,000 r/ | 122,000 |
| Secondary (purchased scrap) 2/ | 54,000 | 58,600 | 64,500 | 59,300 r/ | 68,800 |
| Total | 159,000 | 166,000 | 189,000 | 179,000 r/ | 190,000 |
| Apparent: | | | | | |
| Primary | 122,000 | 134,000 r/ | 151,000 r/ | 147,000 r/ | 154,000 |
| Secondary (purchased scrap) | 36,600 | 30,500 | 29,500 | 33,700 r/ | 38,100 |
| Total | 158,000 | 164,000 | 181,000 | 181,000 r/ | 192,000 |
| Stocks, yearend: | | | | | |
| Government | 31,600 | 26,800 | 19,800 | 15,900 | 8,530 |
| Producers and traders | 15,700 | 10,200 | 12,700 | 13,300 r/ | 12,600 |
| Consumer: | | | | | |
| Primary | 11,100 | 7,290 r/ | 8,230 r/ | 8,850 r/ | 10,300 |
| Secondary | 3,360 | 3,020 | 4,150 | 4,230 r/ | 5,820 |
| Employment, yearend: | | | | | |
| Mine | 2 | 1 | 17 | 8 | 7 |
| Smelter | 33 | 22 | 253 | 253 | 264 |
| Port facility | 5 | 3 | 25 | 23 | 22 |
| Price, cash, London Metal Exchange: | | | | | |
| Per metric ton, average annual | $5,293 | $6,340 | $8,228 | $7,501 | $6,927 |
| Per pound, average annual | $2.401 | $2.876 | $3.732 | $3.402 | $3.142 |
| World: Mine production | 928,000 r/ | 932,000 r/ | 1,050,000 r/ | 1,070,000 r/ | 1,120,000 e/ |

e/ Estimated. p/ Preliminary. r/ Revised.

1/ Data are rounded to three significant digits, except prices; may not add to totals shown.

2/ More nearly represents amount consumed than does apparent secondary consumption; internal evaluation indicates that apparent secondary consumption is considerably understated.

TABLE 2

NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY 1/

(Metric tons of contained nickel)

| | 1996 | 1997 |
|---|---|---|
| Kind of scrap: | | |
| Aluminum-base 2/ | 3,360 r/ | 3,940 |
| Copper-base | 3,120 | 2,390 |
| Ferrous-base 3/ | 48,800 | 58,600 |
| Nickel-base | 4,020 r/ | 3,880 |
| Total | 59,300 r/ | 68,800 |
| Form of recovery: | | |
| Aluminum-base alloys 4/ | 3,360 r/ | 3,940 |
| Copper-base alloys | 4,910 | 3,870 |
| Ferrous alloys | 48,900 r/ | 58,700 |
| Nickel-base alloys | 2,160 | 2,310 |
| Miscellaneous and unspecified | 9 r/ | 22 |
| Total | 59,300 r/ | 68,800 |

r/ Revised.

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Primarily used beverage cans and foundry borings and turnings.

3/ Primarily stainless and alloy steel scrap consumed at steel mills and foundries.

4/ Includes can scrap converted to ingot by toll smelters for sale on open market.

TABLE 3

REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM 1/

(Metric tons of contained nickel)

| Form | 1996 | 1997 |
|---|---|---|
| Primary: | | |
| Metal | 89,200 r/ | 91,100 |
| Ferronickel | 22,900 | 22,500 |
| Oxide and oxide sinter 2/ | 1,520 r/ | 2,890 |
| Chemicals | 4,750 r/ | 3,440 |
| Other | 915 r/ | 1,640 |
| Total primary | 119,000 r/ | 122,000 |
| Secondary (scrap) 3/ | 59,300 r/ | 68,800 |
| Grand total | 179,000 r/ | 190,000 |

r/ Revised.

1/ Data are rounded to 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 IN 1997, BY USE 1/

(Metric tons of contained nickel)

| Use | Metal | Ferro-nickel | Oxide and oxide sinter | Chemicals | Other forms | Total primary | Secondary (scrap) | Grand total 1997 | Grand total 1996 |
|---|---|---|---|---|---|---|---|---|---|
| Cast irons | 168 | W | -- | 1 | 45 | 214 | 428 | 642 | 563 |
| Chemicals and chemical uses | W | -- | W | 2,730 | -- | 2,730 | -- | 2,730 | 5,350 r/ |
| Electric, magnet, expansion alloys | W | W | -- | (2/) | -- | (2/) | W | W | W |
| Electroplating (sales to platers) | 15,800 | -- | W | 61 | 1 | 15,800 | -- | 15,800 | 16,300 r/ |
| Nickel-copper and copper-nickel alloys | 2,650 | W | W | -- | W | 2,650 | 3,390 | 6,040 | 7,280 r/ |
| Other nickel and nickel alloys | 17,000 | W | W | -- | W | 17,000 | 2,040 | 19,100 | 19,300 r/ |
| Steel: | | | | | | | | | |
| Stainless and heat resistant | 26,100 | 21,000 | 1,760 | -- | 57 | 48,900 | 56,900 | 106,000 | 94,100 r/ |
| Alloys (excludes stainless) | 5,180 | 1,090 | 1,060 | (2/) | W | 7,320 | 1,330 | 8,650 | 6,970 r/ |
| Superalloys | 18,200 | -- | (2/) | 1 | 465 | 18,700 | W | 18,700 | 15,600 r/ |
| Other 3/ | 6,000 | 410 | 79 | 645 | 1,070 | 8,210 | 4,790 | 13,000 | 13,300 r/ |
| Total reported | 91,100 | 22,500 | 2,890 | 3,440 | 1,640 | 122,000 | 68,800 | 190,000 | 179,000 r/ |
| Total all companies, apparent | XX | XX | XX | XX | XX | 154,000 | 38,100 | 192,000 | 181,000 r/ |

r/ Revised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Less than 1/2 unit.
3/ Includes batteries, catalysts, ceramics, coinage, other alloys containing nickel, and data indicated by symbol "W."

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

| Form | 1996 | 1997 |
|---|---|---|
| Primary: | | |
| Metal | 6,270 r/ | 7,650 |
| Ferronickel | 1,620 | 1,390 |
| Oxide and oxide sinter | 181 | 355 |
| Chemicals | 483 r/ | 702 |
| Other | 292 r/ | 242 |
| Total primary | 8,850 r/ | 10,300 |
| Secondary (scrap) | 4,230 r/ | 5,820 |
| Grand total | 13,100 r/ | 16,200 |

r/ Revised.
1/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 6
U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS 1/

(Metric tons of contained nickel 2/ unless otherwise specified)

| Class | 1996 Quantity | 1996 Value (thousands) | 1997 Quantity | 1997 Value (thousands) |
|---|---|---|---|---|
| Unwrought primary: | | | | |
| Cathodes, pellets, briquets, shot | 586 | $4,630 | 580 | $4,020 |
| Ferronickel | 3,330 | 32,700 | 6,950 | 53,000 |
| Powder and flakes | 1,060 | 12,600 | 917 | 14,500 |
| Metallurgical-grade oxide | 4,210 | 6,750 | 2,230 | 4,860 |
| Chemicals: | | | | |
| Catalysts | 3,250 | 97,000 | 4,660 | 125,000 |
| Salts 3/ | 692 | 7,980 | 1,030 | 11,600 |
| Total | 13,100 | 162,000 | 16,400 | 213,000 |
| Unwrought secondary: | | | | |
| Stainless steel scrap | 22,800 | 234,000 | 27,700 | 231,000 |
| Waste and scrap | 10,900 | 56,600 | 12,400 | 59,700 |
| Total | 33,600 | 290,000 | 40,200 | 290,000 |
| Grand total | 46,800 | 452,000 | 56,500 | 504,000 |
| Wrought: | | | | |
| Bars, rods, profiles and wire | 157 | 2,300 | 251 | 2,740 |
| Sheets, strip and foil | 188 | 2,720 | 420 | 7,590 |
| Tubes and pipes | 95 | 1,360 | 223 | 2,690 |
| Total | 440 | 6,370 | 892 | 13,000 |
| Alloyed (gross weight): | | | | |
| Unwrought alloyed ingot | 5,710 | 56,600 | 4,910 | 67,900 |
| Bars, rods, profiles and wire | 4,770 | 82,300 | 5,950 | 99,000 |
| Sheets, strip and foil | 8,200 | 113,000 | 8,970 | 118,000 |
| Tubes and pipes | 1,270 | 31,700 | 1,270 | 29,600 |
| Other alloyed articles | 3,520 | 53,100 r/ | 4,010 | 62,800 |
| Total | 23,500 | 336,000 | 25,100 | 377,000 |

r/ Revised.

1/ Data are rounded to 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 (see Schedule B 2836.99.9050).

Sources: Bureau of the Census and Journal of Commerce.

TABLE 7

U.S. EXPORTS OF NICKEL PRODUCTS IN 1997, BY COUNTRY 1/

(Metric tons of contained nickel 2/)

| Country | Cathodes, pellets, and briquets, (unwrought) | Powder and flakes | Ferro-nickel | Metal-lurgical grade oxide 3/ | Waste and scrap | Stainless steel scrap | Chemicals | Total 1997 | Total 1996 | Wrought nickel 4/ |
|---|---|---|---|---|---|---|---|---|---|---|
| Australia | -- | (5/) | -- | -- | 55 | 11 | 14 | 80 | 124 | 4 |
| Belgium | 2 | 86 | -- | 2 | 80 | 163 | 215 | 548 | 388 | 4 |
| Canada | 63 | 352 | -- | 1,220 | 7,210 | 3,000 | 630 | 12,500 | 16,400 | 45 |
| China | -- | 7 | -- | -- | 17 | 42 | 58 | 124 | 270 | 56 |
| Colombia | 1 | 5 | 2 | -- | -- | 5 | 6 | 19 | 69 | 14 |
| Finland | -- | -- | -- | -- | 18 | -- | 12 | 30 | 30 | (5/) |
| France | 17 | 8 | -- | 5 | 54 | -- | 11 | 95 | 74 | 4 |
| Germany | 4 | 49 | -- | 1 | 613 | 44 | 91 | 802 | 768 | 11 |
| India | (5/) | 8 | 2,400 | -- | 39 | 61 | 1 | 2,510 | 1,820 | 40 |
| Italy | (5/) | 3 | -- | -- | -- | 4 | 107 | 114 | 23 | 4 |
| Japan | 1 | 109 | 913 | 151 | 1,230 | 1,850 | 1,420 | 5,670 | 3,880 | 10 |
| Korea, Republic of | (5/) | 61 | -- | 2 | -- | 8,590 | 38 | 8,690 | 6,030 | 160 |
| Mexico | 372 6/ | 76 | 58 | 1 | 2 | 3,690 | 549 | 4,750 | 543 | 184 |
| Netherlands | -- | 14 | -- | 1 | 130 | 269 | 101 | 515 | 269 | 1 |
| South Africa | -- | 2 | 746 | 829 | 120 | 1,300 | 66 | 3,070 | 1,400 r/ | 2 |
| Spain | -- | 17 | -- | -- | -- | 4,470 | -- | 4,490 | 4,860 | -- |
| Sweden | 1 | 8 | -- | -- | 2,650 | 132 | (5/) | 2,790 | 2,670 | 1 |
| Taiwan | -- | 18 | 2,790 | -- | 3 | 3,700 | 294 | 6,800 | 4,540 | 4 |
| United Kingdom | 34 | 28 | 41 | 11 | 89 | 286 | 62 | 551 | 334 | 67 |
| Venezuela | 26 | -- | -- | -- | 5 | 3 | 491 | 525 | 42 | 14 |
| Other | 59 | 66 | -- | 5 | 109 | 136 | 1,520 | 1,900 | 2,240 r/ | 267 |
| Total | 580 | 917 | 6,950 | 2,230 | 12,400 | 27,700 | 5,690 | 56,500 | 46,800 | 892 |

r/ Revised.

1/ Data are rounded to 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 chemical 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/ Chemical-grade oxide is included in the "Chemicals" category.

4/ Not included in "Total."

5/ Less than 1/2 unit.

6/ Includes products of Norwegian origin.

Source: Bureau of the Census.

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

(Metric tons of contained nickel 2/ unless otherwise specified)

| Class | 1996 Quantity | 1996 Value (thousands) | 1997 Quantity | 1997 Value (thousands) |
|---|---|---|---|---|
| Unwrought primary: | | | | |
| Cathodes, pellets, briquets, shot | 113,000 | $890,000 | 118,000 | $825,000 |
| Ferronickel | 16,000 | 111,000 | 13,500 | 87,700 |
| Flakes | 1 | 55 | 17 | 325 |
| Powder | 9,690 r/ | 101,000 | 10,500 | 112,000 |
| Metallurgical-grade oxide | 463 r/ | 4,220 | 1,940 | 16,000 |
| Chemicals: | | | | |
| Catalysts | 1,540 | 61,500 | 1,320 | 51,700 |
| Salts 3/ | 1,730 | 22,800 | 1,900 | 23,100 |
| Total | 142,000 | 1,190,000 | 147,000 | 1,120,000 |
| Unwrought secondary: | | | | |
| Stainless steel scrap | 3,790 | 28,500 | 4,800 | 33,700 |
| Waste and scrap | 4,270 r/ | 35,200 | 6,200 | 53,600 |
| Total | 8,060 | 63,800 | 11,000 | 87,300 |
| Grand total | 150,000 | 1,250,000 | 158,000 | 1,200,000 |
| Wrought: | | | | |
| Bars, rods, profiles and wire | 242 | 3,750 | 348 | 4,420 |
| Sheets, strip and foil | 341 | 9,090 | 602 | 13,900 |
| Tubes and pipes | 54 | 1,230 | 22 | 921 |
| Total | 636 | 14,100 | 973 | 19,300 |
| Alloyed (gross weight): | | | | |
| Unwrought alloyed ingot | 2,780 | 28,300 | 3,730 | 38,600 |
| Bars, rods, profiles and wire | 3,920 | 58,500 | 5,440 | 70,400 |
| Sheets, strip and foil | 1,520 | 24,800 | 2,020 | 29,900 |
| Tubes and pipes | 832 | 17,500 | 1,990 | 42,700 |
| Other alloyed articles | 1,190 | 18,700 | 802 | 21,800 |
| Total | 10,200 | 148,000 | 14,000 | 203,000 |

r/ Revised.
1/ Data are rounded to 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 (see HTSUS 2836.99.5000).

Sources: Bureau of the Census and Journal of Commerce.

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

(Metric tons of contained nickel 2/)

| Country | Cathodes, pellets, and briquets (unwrought) | Powder and flakes | Ferro-nickel | Metal-lurgical grade oxide 3/ | Waste and scrap | Stainless steel scrap | Chemicals | Total | | Wrought nickel 4/ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 1997 | 1996 | |
| Australia | 12,300 | 1,340 | -- | 76 | 28 | -- | 11 | 13,700 | 14,900 | -- |
| Austria | 60 | 513 | 3 | -- | -- | -- | -- | 577 | 274 | 28 |
| Belgium | -- | 6 | -- | -- | 53 | -- | 391 | 451 | 344 | (5/) |
| Brazil | 548 | -- | 275 | -- | 8 | 1 | -- | 833 | 501 | -- |
| Canada | 46,900 | 7,200 | -- | 1,860 | 1,700 | 2,550 | 402 | 60,600 | 58,500 | 17 |
| China | -- | (5/) | -- | -- | 25 | 1 | 104 | 131 | 27 | 2 |
| Colombia | -- | -- | 1,430 | -- | -- | -- | -- | 1,430 | 1,420 | -- |
| Dominican Republic | -- | -- | 8,070 | -- | 90 | 2 | -- | 8,160 | 9,290 | -- |
| Finland | 3,680 | 773 | -- | -- | -- | -- | 468 | 4,920 | 4,740 | -- |
| France | 1,350 | (5/) | -- | -- | 788 | 12 | 171 | 2,320 | 2,260 | 118 |
| Germany | 35 | 15 | 1 | -- | 438 | 7 | 284 | 780 | 819 r/ | 672 |
| Japan | -- | 201 | -- | (5/) | 126 | 79 | 695 | 1,100 | 1,160 | 101 |
| Mexico | -- | -- | -- | -- | 126 | 2,020 | 239 | 2,380 | 1,940 | 1 |
| New Caledonia | -- | -- | 3,470 | -- | -- | -- | -- | 3,470 | 4,160 | -- |
| Norway | 24,000 | -- | -- | -- | 28 | -- | -- | 24,100 | 24,300 | -- |
| Russia | 25,300 | 212 | 56 | -- | 12 | -- | 8 | 25,600 | 18,700 r/ | -- |
| South Africa | 1,440 | -- | 22 | -- | -- | -- | 9 | 1,470 | 1,200 | -- |
| United Kingdom | 931 | 148 | -- | (5/) | 1,580 | -- | 196 | 2,850 | 1,940 | 13 |
| Zimbabwe | 1,740 | -- | -- | -- | -- | -- | -- | 1,740 | 1,730 | -- |
| Other | 18 | 56 | 182 | 13 | 1,200 | 138 | 243 | 1,850 | 2,160 r/ | 21 |
| Total | 118,000 | 10,500 | 13,500 | 1,940 | 6,200 | 4,800 | 3,220 | 158,000 | 150,000 | 973 |

r/ Revised.
1/ Data are rounded to 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%; and other salts which are assumed to be 22% nickel. The typical catalysts are assumed to have a content of 22%.
3/ Primarily oxide rondelles and sinter.
4/ Not included in "Total."
5/ Less than 1/2 unit.

Source: Bureau of the Census.

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

(Metric tons of nickel content)

| Country | 1993 | 1994 | 1995 | 1996 | 1997 e/ |
|---|---|---|---|---|---|
| Albania (content of ore) e/ | 75 | -- | -- | -- | -- |
| Australia (content of concentrate) | 64,717 | 78,962 | 98,467 | 113,134 | 124,000 3/ |
| Botswana (content of ore milled) | 21,621 r/ | 19,041 | 18,088 r/ | 22,095 r/ | 20,157 3/ |
| Brazil (content of ore) | 32,154 | 27,706 r/ | 29,124 r/ | 25,245 r/ | 25,300 |
| Burma (content of ore) e/ | 67 3/ | 50 | 50 | 50 | 50 |
| Canada (content of concentrate) | 188,080 | 149,886 | 181,820 r/ | 192,649 r/ | 190,529 p/ |
| China e/ | 30,700 | 36,900 | 41,800 | 43,800 r/ | 44,000 |
| Colombia (content of laterite ore) | 22,831 | 26,141 | 24,194 | 27,700 r/ | 31,230 3/ |
| Cuba (content of oxide, oxide sinter, sulfide) 4/ | 28,972 r/ | 25,787 r/ | 40,845 r/ | 51,289 r/ | 59,000 |
| Dominican Republic (content of laterite ore) | 37,423 | 50,146 r/ | 51,500 r/ | 50,567 r/ | 52,000 |
| Finland (content of concentrate) | 8,862 | 7,652 | 3,439 r/ | 3,872 r/ | 3,252 3/ |
| Greece (content of laterite ore) | 12,940 | 18,821 | 19,947 | 21,600 r/ | 18,419 3/ |
| Indonesia (content of ore) | 65,757 | 81,175 | 88,183 | 87,911 r/ | 72,200 |
| Kazakstan e/ | 8,500 | 8,500 | 9,900 3/ | 9,800 | 10,000 |
| Macedonia (content of ferronickel produced) | 4,493 | 3,980 | 3,500 | 3,000 e/ | 3,000 |
| New Caledonia (content of ore) | 97,092 | 97,323 | 121,457 | 124,800 r/ | 137,068 3/ |
| Norway (content of concentrate) | 3,462 | 3,328 r/ | 3,386 r/ | 3,135 r/ | 2,454 3/ |
| Philippines | 7,663 | 9,895 | 15,075 | 14,539 r/ | 18,132 3/ |
| Russia e/ | 244,000 3/ | 240,000 | 251,000 | 230,000 | 260,000 |
| Serbia and Montenegro (content of ferronickel produced) | 443 | 603 | 962 | 2,556 | 2,500 |
| South Africa (content of concentrate) | 29,868 | 30,751 | 29,803 | 33,861 r/ | 34,830 3/ |
| Ukraine (content of ferronickel produced) e/ | 3,000 | 1,400 3/ | 1,400 | 500 | -- |
| United States (content of local ore processed) | 2,460 | -- | 1,560 | 1,330 | -- 3/ |
| Zimbabwe (content of concentrate) | 12,769 | 13,836 | 11,721 | 11,561 r/ | 11,000 |
| Total | 928,000 r/ | 932,000 r/ | 1,050,000 r/ | 1,070,000 r/ | 1,120,000 |

e/ Estimated. p/ Preliminary. r/ Revised.
1/ World totals, U.S. data, and estimated data are rounded to 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 also have an active mine, but information is inadequate to make reliable estimates of output. Table includes data available through October 6, 1998.
3/ Reported figure.
4/ Data represent nickel plus cobalt content in the ratio of approximately 80 to 1.

TABLE 11

NICKEL: WORLD PLANT PRODUCTION BY COUNTRY AND PRODUCT 1/ 2/

(Metric tons of nickel content)

| Country 3/ and product | 1993 | 1994 | 1995 | 1996 e/ | 1997 |
|---|---|---|---|---|---|
| Albania: Metal e/ | 50 | 50 | 50 | 50 | -- |
| Australia: Unspecified | 55,000 | 67,000 | 77,000 | 74,000 | 74,000 4/ |
| Austria: Ferronickel e/ | 3,200 4/ | 2,100 | 2,500 | 2,000 | 2,000 |
| Brazil: 5/ | | | | | |
| Ferronickel | 8,683 | 8,815 | 8,497 | 9,091 r/ | 9,100 |
| Metal | 7,022 | 7,795 | 7,179 | 7,849 r/ | 7,900 |
| Total | 15,705 | 16,610 | 15,676 | 16,940 r/ | 17,000 |
| Canada: Unspecified 6/ | 123,140 | 105,144 | 121,523 | 126,593 | 127,294 4/ |
| China: Metal e/ | 30,500 | 31,300 | 38,900 | 44,600 r/ | 40,000 |
| Colombia: Ferronickel | 20,181 | 20,833 | 24,565 | 22,934 | 23,000 |
| Cuba: Oxide sinter 7/ | 15,999 | 13,930 | 21,388 | 26,700 r/ | 33,600 |
| Dominican Republic: Ferronickel | 23,859 | 30,757 r/ | 30,897 r/ | 30,376 r/ | 32,558 4/ |
| Finland: | | | | | |
| Chemicals | 3,126 | 4,192 | 4,000 e/ | 4,000 e/ | 4,000 |
| Metal | 14,800 | 16,902 | 16,927 | 28,815 r/ | 34,228 4/ |
| Total | 17,926 | 21,094 | 20,900 e/ | 32,800 r/ e/ | 38,200 |
| France: | | | | | |
| Chemicals e/ | 1,200 | 1,200 | 1,200 | 1,000 r/ | 1,000 |
| Metal | 9,120 | 10,041 | 10,306 | 11,167 r/ | 10,701 4/ |
| Total e/ | 10,300 | 11,200 | 11,500 | 12,200 r/ | 11,700 |
| Greece: Ferronickel | 10,934 | 16,197 | 17,164 | 17,801 r/ | 17,600 4/ |
| Indonesia: Ferronickel | 5,266 | 5,745 | 10,735 | 11,000 e/ | 9,994 4/ |
| Japan: | | | | | |
| Ferronickel | 51,120 | 50,186 | 69,876 | 66,796 r/ | 70,000 |
| Metal | 23,108 | 25,311 | 26,824 | 26,564 | 26,900 |
| Oxide sinter | 28,812 | 34,711 | 35,966 | 36,200 | 37,000 |
| Chemicals | 2,258 | 2,400 | 2,297 | 2,344 | 2,400 |
| Total | 105,298 | 112,608 | 134,963 | 131,904 r/ | 136,000 |
| Korea, Republic of: Metal e/ | (8/) | (8/) | (8/) | (8/) | (8/) |
| New Caledonia: Ferronickel | 36,850 | 39,488 | 42,200 | 42,200 r/ | 44,300 4/ |
| Norway: Metal | 56,817 | 67,955 | 53,237 | 61,582 | 62,702 4/ |
| Russia: e/ 9/ | | | | | |
| Ferronickel | 6,800 | 9,800 | 14,000 | 10,000 | 10,000 |
| Metal | 167,000 | 165,000 | 181,000 | 175,000 | 210,000 |
| Oxide sinter | 10,800 r/ | 4,600 | 4,100 | 3,000 | 8,000 |
| Chemicals | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Total | 187,000 r/ | 181,000 | 201,000 | 190,000 | 230,000 |
| Serbia and Montenegro: Ferronickel | 443 | 603 | 962 | 2,556 | 2,500 |
| South Africa: Metal | 29,868 | 30,751 | 29,803 | 33,600 r/ | 33,700 |
| Sweden: Metal e/ | 500 | 500 | 500 | -- r/ | -- |
| Taiwan: Metal | (8/) | (8/) | (8/) | (8/) | (8/) |
| Ukraine: Ferronickel e/ | 3,000 | 1,400 | 1,400 | 500 | -- |
| United Kingdom: Metal e/ | 28,000 e/ | 28,400 | 35,156 r/ | 38,561 r/ | 36,586 4/ |
| United States: Ferronickel | 4,880 | -- | 8,290 | 15,100 4/ | |
| Zimbabwe: Metal 10/ | 11,097 | 13,516 | 10,864 | 9,674 r/ | 9,500 |
| Grand total | 795,000 | 818,000 | 911,000 r/ | 944,000 r/ | 983,000 |
| Of which: | | | | | |
| Ferronickel | 175,000 | 186,000 | 231,000 | 230,000 r/ | 221,000 |
| Metal | 378,000 | 397,000 | 411,000 r/ | 437,000 r/ | 472,000 |
| Oxide sinter | 55,600 r/ | 53,200 | 61,500 | 65,900 r/ | 78,600 |
| Chemicals | 8,580 | 9,790 | 9,500 | 9,340 r/ | 9,400 |
| Unspecified | 178,000 | 172,000 | 199,000 | 201,000 | 201,000 |

e/ Estimated. r/ Revised.

1/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through July 29, 1998.

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. Between 1993 and 1997, the Republic of Korea, the United States, and five members of the European Union reported receiving ferronickel originating from Macedonia, but definitive information on the output of the Kavadarci operation was not available. Data supplied by the International Nickel Study Group suggest that, since 1991, Macedonian ferronickel production has ranged from 2,000 to 4,500 metric tons per year of contained nickel. Several countries produce nickel-containing matte, but output of nickel in such materials has been excluded from this table in order to avoid double counting. Countries producing matte include the following, with output indicated in metric tons of contained nickel: Australia (revised): 1993--55,000; 1994--67,000; 1995--77,000; 1996--74,000; and 1997--74,000; Botswana: 1993--19,619; 1994--19,042; 1995--18,089; 1996--22,095 (revised); and

1997--20,157; Canada (estimated average per year):  1993-97--40,000; Indonesia:  1993--37,000; 1994--48,400; 1995--49,300; 1996--49,000; and 1997--31,800; New Caledonia:  1993--10,883; 1994--10,641; 1965--10,143; 1996--9.850; and 1997--10,150.

4/ Reported figure.

5/ Brazil produced nickel carbonate, in metric tons:  1993--8,044; 1994--8,930; 1995--8,051; 1996--9,210; and 1997--9,200 (estimated).

6/ Nickel contained in products of smelters and refineries in forms which are ready for use by consumers.

7/ Cuba also produces nickel sulfide but, because it is used as feed material elsewhere, it is not included to avoid double counting.  Output of  processed sulfide was as follows, in metric tons of contained nickel:  1993--12,973; 1994--11,857; 1995--19,457 (revised); 1996--24,589; and 1997--25,400 (estimated).

8/ Nickel metal production figures for the Republic of Korea and Taiwan are not included because the production is derived wholly from imported metallurgical oxides and to include them would result in double counting.  Metal estimates are as follows in metric tons:  the Republic of Korea:  1993-96--10,000; and 1997--20,000; Taiwan:  1993--9,000; 1994-96--10,000; and 1997--10,500.

9/ Includes production from sulfidized concentrates shipped from Cuba for toll refining.

10/ Excludes production from matte shipped from Botswana for toll refining.