5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.1 PRODUCTION

Nickel ranks 24th in order of abundance in the earth's crust, with an average concentration of 0.0086%. Its crustal concentration varies from ≤0.0001 to >0.3%. Economically exploitable ore deposits typically contain 1–3% nickel. The concentration of nickel increases towards the center of the earth, and nickel is estimated to comprise 0.22% of the earth's mantle and 5.8% of its core (Duke 1980a). Overall, it is the fifth most abundant element on Earth after iron, oxygen, magnesium, and silicon. Nickel is found combined with iron in meteorites; the nickel content ranges from 5 to 50% (Duke 1980a; Mastromatteo 1986). It is also found in sea floor nodules (Mastromatteo 1986).

Nickel ores are of two general types: magmatic sulfide ores, which are mined underground, and lateritic hydrous nickel silicates or garnierites, which are surface mined (Duke 1980a; Warner 1984).

The most important nickel sulfide-arsenide deposits are in hydrothermal veins associated with mafic (i.e., rich in magnesium and iron) and ultramafic igneous rock. These ores typically contain 1–3% nickel. Pentlandite $(Ni,Fe)_9S_8$ is the principle ore. Pentlandite often occurs along with the iron mineral pyrrhotite and the copper mineral chalcopyrite, and part of the smelting and refining process separates the copper and iron from the nickel. The ore is concentrated by physical means (i.e., flotation and magnetic separation) after crushing. One of the largest sulfidic nickel deposits is in Sudbury, Ontario, Canada. Nickeliferous sulfide deposits are also found in Thompson, Manitoba, Canada; South Africa; Russia (primarily Siberia); Finland; western Australia; and Minnesota (Ademec and Kihlgren 1967; Duke 1980a).

The lateritic hydrous nickel silicate ores are formed by the weathering of rocks rich in iron and magnesium in humid tropical areas. The repeated processes of dissolution and precipitation lead to a uniform dispersal of the nickel that is not amenable to concentration by physical means; therefore, these ores are concentrated by chemical means such as leaching. Lateritic ores are less well defined than sulfide ores. The nickel content of lateritic ores is similar to that of sulfide ore and typically ranges from 1 to 3% nickel. Important lateritic deposits of nickel are located in Cuba, New Caledonia, Indonesia, Guatemala, the Dominican Republic, the Philippines, and Brazil. Fossil nickeliferous laterite deposits are found in Oregon, Greece, and the former Soviet Union, where humid, tropical climates prevailed in the past. Lateritic deposits constitute the largest nickel reserves (Ademec and Kihlgren 1967; Antonsen and Springer 1967; Duke 1980a). Thirty-five percent of known nickel reserves are in Cuba (Kirk 1988b).

Sulfide ores are processed by a number of pyrometallurgical processes: roasting, smelting, and converting. During these processes, sulfur and iron are removed to yield a sulfur-deficient copper-nickel matte. Especially after roasting and converting, the nickel in the matte may consist primarily of nickel subsulfide. After physical separation of the copper and nickel sulfides, the nickel is refined electrochemically or by the carbonyl process. The treatment of the matte depends on the end use of the nickel. Alternatively, the sulfide can be roasted to form a nickel oxide sinter that is used directly in steel production.

Lateritic ore is processed by pyrometallurgical or hydrometallurgical processes. In the pyrometallurgical process, sulfur is generally added to the oxide ore during smelting, usually as gypsum or elemental sulfur, and an iron-nickel matte is produced. The smelting process that does not include adding sulfur produces a ferronickel alloy, containing ≤50% nickel, which can be used directly in steel production. Hydro-metallurgical techniques involve leaching with ammonia or sulfuric acid, after which the nickel is selectively precipitated (Duke 1980b; IARC 1990; Tien and Howson 1981; Warner 1984). Alloys, such as stainless steels, are produced by melting primary metals and scrap in large arc furnaces and adjusting the carbon content and concentration of alloying metals to the desired levels. More information on the mining, smelting, and refining of nickel can be found in Duke (1980b), Tien and Howson (1981), and Warner (1984).

Domestic primary nickel production in the United States ceased in 1986 (Chamberlain 1985; Kirk 1988a) with the closing of the Hanna mine and smelter in Riddle, Oregon, and the AMAX refinery in Braithwaite, Louisiana. However, Glenbrook Nickel Company purchased the Riddle, Oregon, facility in 1989 and had reactivated the mining and smelting operation, but then decommissioned both the mining and smelting operations in 2000. World mine production of nickel in 2001 was estimated at 1,330,000 metric tons (Kuck 2001). Secondary nickel production from scrap is a major source of nickel for industrial applications. In 1988, an estimated 59,609 and 3,700 short tons of nickel were produced from ferrous and nonferrous scrap, respectively. Nickel recovery from scrap is estimated by using the gross weight of the scrap and a weighted average nickel content (e.g., 7.5% for stainless steel). The secondary recovery from ferrous scrap was considerably higher and the recovery from nonferrous scrap was considerably lower than for the previous 7 years in which the annual recovery of nickel from ferrous and nonferrous scrap ranged from 30,034 to 389,265 short tons and from 8,392 to 19,776 short tons, respectively. The production of refined nickel in 1993 has been estimated as 220,700, 346,800, 176,200, 52,100, and 96,300 short tons for North America, Europe, Asia, Africa, and Australia, respectively (ABMS 1994). In 1994, the world distribution of refined nickel production was 21%, Russia (Commonwealth of Independent States); 17%, Western Europe; 14%, Japan; 13%, Canada; 13%, Australia/New Caledonia; 6%, Africa; 4%, Dominican Republic; 4%, China; and 8%, Brazil, Columbia, Cuba, Eastern Europe, Indonesia, and the United States (Anderson 1995). The reported world consumption of refined nickel was 1,150,800 metric tons in 2001, up from 997,800 metric tons in 1997 (ABMS 2002).

Tables 5-1 and 5-2 list the facilities that produced, imported, processed, or used nickel and its compounds, respectively, in 2001 according to reports made to the EPA under the requirements of Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986, which were subsequently published in the Toxic Chemical Release Inventory (TRI) (TRI01 2003). Companies were required to report if they produced, imported, or processed ≥75,000 pounds of nickel and its compounds or used >10,000 pounds. Also included in Tables 5-1 and 5-2 are the maximum amount of nickel and its compounds, respectively, that these facilities had on site and whether nickel was produced, processed, or used by the facility.

5.2 IMPORT/EXPORT

In 2001, the United States imported 144,000 metric tons of nickel, including 110,000 metric tons of unwrought metal, 8,310 metric tons of powder and flakes, 11,600 metric tons of ferronickel, 5,580 metric tons of nickel waste and scrap, 3,180 metric tons stainless steel scrap, 1,350 metric tons of oxide and oxide sinter, and 3,200 metric tons of nickel salts (Kuck 2001). In 2001, Canada supplied the largest share of primary nickel, 60,700 metric tons (42%). Norway was the second largest exporter of primary nickel to the United States with 18,900 metric tons (13%) followed by Australia and Russia with 17,200 and 9,280 metric tons, respectively. The 144,000 metric tons of nickel imported in 2001 was down from the 158,000 and 167,000 metric tons imported in 1996 and 2000, respectively (Kuck 1997, 2001). From 1980 to 1985, nickel imports as a percentage of consumption ranged from 68 to 76%. This is comparable to the figures for 2000 and 2001 of 84 and 72%, respectively (Kuck 2001).

The amount of exported nickel dropped sharply in 1986 to 15,217 short tons from 35,245 short tons the previous year (Kirk 1988a), which coincided with the cessation of primary nickel production in the United States. The nickel content of exported primary and secondary nickel in 2001 was 57,000 metric tons, most of which was in the form of unwrought metal (Kuck 2001).

Table 5-1. Facilities that Produce, Process, or Use Nickel Metal

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AL	42	100	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
AR	28	100	999,999	1, 7, 8, 11, 12, 13
AZ	17	0	9,999,999	1, 4, 5, 7, 8, 9, 10, 11, 12
CA	91	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
CO	11	1,000	999,999	2, 3, 4, 6, 7, 8, 11, 12
CT	47	100	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
DE	1	10,000	99,999	8
FL	20	0	499,999,999	7, 8, 10, 11
GA	30	0	999,999	1, 2, 3, 5, 7, 8, 10, 11, 12, 14
IA	43	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
ID	1	100,000	999,999	1, 3, 12
IL	111	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
IN	128	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
KS	17	100	999,999	8, 9, 11, 12, 14
KY	42	0	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 14
LA	20	0	49,999,999	1, 2, 3, 5, 6, 7, 8, 10, 13, 14
MA	43	1,000	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 12
MD	5	10,000	999,999	2, 4, 8, 9
ME	9	1,000	9,999,999	1, 3, 7, 8, 12
MI	105	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14
MN	36	1,000	999,999	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14
MO	37	0	9,999,999	1, 2, 3, 5, 6, 7, 8, 10, 12
MS	19	1,000	9,999,999	2, 3, 7, 8, 12
MT	1	100	999	6, 11
NC	50	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
ND	6	10,000	999,999	2, 3, 7, 8, 9, 12
NE	15	100	999,999	1, 2, 3, 5, 8, 9, 11
NH	9	100	99,999	8
NJ	19	1,000	49,999,999	1, 2, 3, 4, 7, 8, 9, 11, 13
NM	5	100	999,999	2, 3, 6, 7, 8, 10, 11
NV	4	10,000	99,999	1, 5, 8, 12
NY	58	0	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 11, 12
OH	173	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OK	47	1,000	999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
OR	17	1,000	999,999	1, 2, 3, 4, 7, 8, 9, 11, 12
PA	198	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
PR	2	1,000	99,999	8, 12
RI	7	100	999,999	2, 3, 7, 8, 9
SC	40	0	9,999,999	1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13
SD	6	1,000	999,999	1, 5, 8

Table 5-1. Facilities that Produce, Process, or Use Nickel Metal

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
TN	45	100	999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
TX	103	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
UT	14	1,000	999,999	1, 3, 4, 7, 8, 11, 12
VA	15	100	999,999	1, 4, 5, 6, 7, 8, 9, 12, 13, 14
VT	3	1,000	99,999	2, 4, 8, 11
WA	13	0	999,999	2, 3, 7, 8, 9
WI	136	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14
WV	13	100	999,999	2, 3, 6, 7, 8, 9, 12
WY	3	1,000	99,999	1, 4, 8, 9, 12

Source: TRI01 2003

[a]Post office state abbreviations used
[b]Amounts on site reported by facilities in each state
[c]Activities/Uses:

1. Produce
2. Import
3. Onsite Use/Processing
4. Sale/Distribution
5. Byproduct
6. Impurity
7. Reactant
8. Formulation Component
9. Article Component
10. Repackaging
11. Chemical Processing Aid
12. Manufacturing Aid
13. Ancillary/Other Uses
14. Process Impurity

Table 5-2. Facilities that Produce, Process, or Use Nickel Compounds

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AK	4	10,000	9,999,999	1, 2, 3, 5, 7, 10, 11, 12
AL	28	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
AR	13	10,000	999,999	1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13, 14
AZ	12	100	99,999,999	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 13, 14
CA	59	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
CO	9	100	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12
CT	24	100	999,999	1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13
DC	1	10,000	99,999	1, 3, 11
DE	7	1,000	999,999	1, 2, 3, 5, 6, 7, 9, 10, 12, 13
FL	20	0	999,999	1, 2, 3, 4, 5, 6, 8, 9, 12, 13, 14
GA	22	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14
HI	1	1,000	9,999	1, 5, 12
IA	16	100	9,999,999	1, 3, 5, 7, 8, 9, 10, 12, 13, 14
ID	3	100,000	999,999	1, 5, 8
IL	82	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
IN	76	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
KS	13	0	999,999	1, 5, 7, 8, 9, 10, 11, 12, 13
KY	41	100	499,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
LA	30	100	999,999	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14
MA	15	100	9,999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 12
MD	11	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13
ME	3	100	99,999	1, 5, 8, 11, 13
MI	66	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
MN	23	100	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
MO	32	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
MS	15	1,000	999,999	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
MT	6	0	9,999,999	1, 2, 3, 4, 5, 6, 12, 13, 14
NC	25	0	999,999	1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
ND	4	1,000	9,999	1, 5, 12, 13, 14
NE	8	100	999,999	1, 3, 4, 5, 7, 8, 9, 10, 12, 13
NH	5	100	99,999	1, 5, 7, 8, 9
NJ	15	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
NM	6	10,000	999,999	1, 3, 4, 5, 9, 11, 12, 13
NV	10	100	10,000,000,000	1, 5, 6, 9, 10, 12, 13, 14
NY	26	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
OH	84	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OK	16	100	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OR	10	1,000	9,999,999	1, 5, 7, 8, 11, 12
PA	104	0	99,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Table 5-2. Facilities that Produce, Process, or Use Nickel Compounds

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
PR	5	100	99,999	1, 2, 5, 10, 13
RI	6	100	999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11
SC	29	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14
SD	1	10,000	99,999	1, 5, 9, 13
TN	37	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
TX	81	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
UT	8	10,000	49,999,999	1, 2, 3, 4, 5, 7, 9, 11, 12, 13, 14
VA	21	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
VI	1	100,000	999,999	10
WA	6	10,000	999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 13
WI	41	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
WV	17	0	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14
WY	3	100	99,999	1, 5, 9, 12, 13

Source: TRI01 2003

[a]Post office state abbreviations used
[b]Amounts on site reported by facilities in each state
[c]Activities/Uses:

1. Produce
2. Import
3. Onsite Use/Processing
4. Sale/Distribution
5. Byproduct
6. Impurity
7. Reactant
8. Formulation Component
9. Article Component
10. Repackaging
11. Chemical Processing Aid
12. Manufacturing Aid
13. Ancillary/Other Uses
14. Process Impurity

5.3 USE

Nickel is primarily used in alloys because it imparts to a product such desirable properties as corrosion resistance, heat resistance, hardness, and strength. Nickel alloys are often divided into categories depending on the primary metal with which they are alloyed and their nickel content. Copper-nickel alloys (e.g., Monel alloys) are used for industrial plumbing, marine equipment, petrochemical equipment, heat exchangers, pumps, and electrodes for welding. Coinage metal contains 75% copper and 25% nickel. Nickel-chromium alloys (e.g., Nichrome) are used for heating elements. Nickel-iron-chromium alloys (e.g., Inconel) provide strength and corrosion resistance over a wide temperature range. Hastelloy alloys, which contain nickel, chromium, iron, and molybdenum, provide oxidation and corrosion resistance for use with acids and salts. Nickel-based superalloys have the required high-temperature strength and creep and stress resistance for use in gas-turbine engines. Nickel silvers, and nickel alloys with zinc and copper, have an attractive white color and are used for coatings on tableware and as electrical contacts. Raney nickel, 50% aluminum and 50% nickel, is used as a catalyst in hydrogenation reactions. Large amounts of nickel are alloyed with iron to produce alloy steels, stainless steels, and cast irons. Stainless steel may contain as much as 25–30% nickel, although 8–10% nickel is more typical. Alloy steels generally contain 0.3–5% nickel. In addition to imparting characteristics such as strength, toughness, corrosion resistance, and machinability, some applications make use of nickel's magnetic characteristics. Most permanent magnets are made of alloys of iron and nickel (Tien and Howson 1981).

Nickel salts are used in electroplating, ceramics, pigments, and as catalysts. Sinter nickel oxide is used as charge material in the manufacture of alloy steel and stainless steel. Nickel is also used in alkaline (nickel-cadmium) batteries.

The distribution of nickel consumption by use in 2001 was as follows: stainless and heat-resistant steel, 60%; nonferrous alloys, excluding superalloys, 4%; nickel-copper, copper-nickel and other nickel alloys, 6%; electroplating, 6%; superalloys, 9%; and other, 10%. Other uses include cast iron; chemicals and chemical use; electric, magnet, expansion alloys; steel alloys, other than stainless steel; batteries; and ceramics. Eighty-six percent of nickel consumption was for the production of nickel metal and alloys (Kuck 2001).

5.4 DISPOSAL

Little information concerning the disposal of nickel and its compounds is found in the literature. Much of the nickel used in metal products (e.g., stainless steel, nickel plate, various alloys) is recycled, which is evident from the fact that 48% of nickel consumption in 2001 was derived from secondary scrap (Kuck 2001). According to the 2001 TRI, 95.3% of the 56,119,316 pounds (25,478,169 kg) of nickel and nickel compounds released on-site is released to land (see Section 6.1) (TRI01 2003). In addition, >21 million pounds of nickel were transferred to off-site locations that year with about 90% being recycled. Steel and other nickel-containing items discarded by households and commercial establishments are generally recycled, landfilled, or incinerated along with normal commercial and municipal trash.

Nickel is removed from electroplating wastes by treatment with hydroxide, lime, and/or sulfide to precipitate the metal (HSDB 2003). Adsorption with activated carbon, activated alumina, and iron filings is also used for treating nickel-containing waste water. Ion exchange is also used for nickel removal and recovery.

Nickel and its compounds have been designated as toxic pollutants by EPA pursuant to Section 307(a)(1) of the Federal Water Pollution Control Act (40 CFR 401.15). As such, permits are issued by the states under the National Pollutant Discharge Elimination System (NPDES) for discharges of nickel that meet the applicable requirements (40 CFR 401.12).