Vanadium

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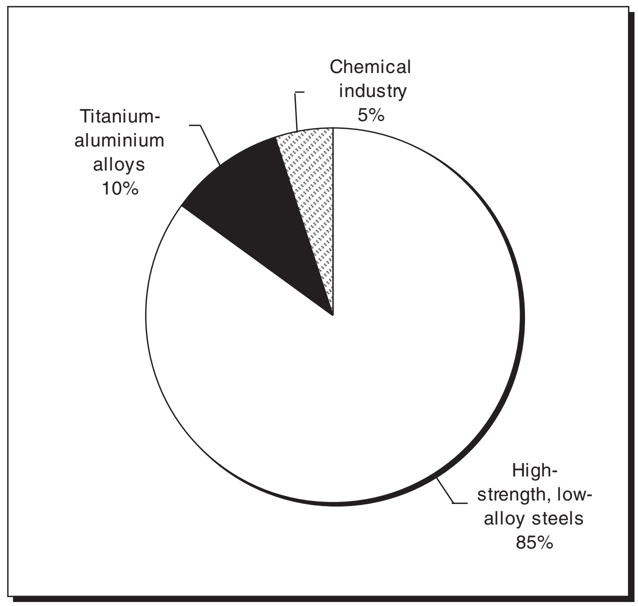
Vanadium, element no. 23 of Mendeleyev's periodic table, is listed as the 22nd most abundant element on earth and is found in a large number of minerals, of which the most important are carnotite, roscoelite, vanadinite, mottramite and patronite. However, because vanadium is usually recovered as a by-product or co-product, it is generally sourced in its primary state from deposits of titaniferrous magnetite, phosphate and uranium, as well as from crude oils where it is found as a minor element. Vanadium can also be sourced by recycling spent catalysts from the petrochemical industry and ash produced by the combustion of oil emulsion in power stations. However, recycling activities are believed to account for only a few percent of total world supply.

Vanadium's main industrial use, 85% of consumption, is in the production of high-strength, low-alloy steels (HSLA) and tool and die steels. Another 10% is used in the manufacture of titanium-aluminum alloys for the aerospace industry while about 5% is used in the chemical industry (Figure 1).

Figure 1
Vanadium, Use by Industry Sector



Source: United States Geological Survey.

Vanadium is used in the steel industry for its property as an active grain refiner and as a strong deoxidant, and can impart strength, hardness and wear resistance to steels. Additions to steel are made primarily in the form of ferrovanadium, which is produced mostly by using the aluminothermic process or an electric furnace. With the aluminothermic process, a mixture of vanadium pentoxide, aluminum, ferrous scrap and a flux is charged to a refractory-lined open steel crucible. The reaction is initiated by using a fuse of barium pentoxide mixed with aluminum or magnesium powder to ignite the charge. If an electric furnace is used, less aluminum is needed and less vanadium is lost to the slag, but the process is more energy-intensive.

In the steel industry, HSLA steels have gradually replaced carbon steels in many instances where the higher intrinsic strength of HSLA steel permits a lower design weight that can offset the somewhat higher per-unit weight cost to better compete against aluminum products. The lighter weight results in savings in energy consumption costs in the transportation industry while the addition of vanadium improves the weldability of the steels. The major uses of HSLA steels are in pipelines, concrete reinforcing bars, structural shapes, tool steels, and automobile components. In these applications, niobium and vanadium are largely interchangeable. The superalloy industry uses vanadium mainly for aircraft applications, such as for turbine blades and jet engines where high-temperature strength is essential.

In the nonferrous sector, vanadium's main use is as a stabilizer in titanium-aluminum alloys used in the aerospace industry. In this application there is essentially no substitute for vanadium as a strengthening element. In the chemical industry, vanadium compounds are used in oxidation catalysts for the production of sulphuric acids and the cracking of petroleum products. It is also used as a glass and ceramic pigment, in permanent magnets, in dryers in paints and varnishes, in the processing of colour films, as a strengthening element in aluminum alloys, in small rechargeable batteries, and in catalysts for the control of exhaust fumes in diesel engines.

Current research on the use of vanadium in electrochemical energy storage systems may also open a new niche market and create significant growth prospects for the industry over the short to medium term. Vanadium Redox Flow Batteries (VRFB) use the chemical characteristics of vanadium to store electrical energy as chemical energy. Connected to an electrical grid, VRFB can be charged and discharged at will, making them an excellent back-up energy supply during power outages. VRFB can also be used to store electricity overnight for use during peak periods to take advantage of lower electricity rates or it can be used in electrical load levelling in power-generating units to prevent current fluctuations, which create problems for high-tech devices. So far, large-scale grid-connected units have been in demonstration in Japan, Australia, the Republic of South Africa (RSA) and the United States of America over the past few years and could be commercialized soon.

CANADIAN DEVELOPMENTS

Vanadium occurrences are widespread throughout Canada. However, the most common type of occurrence is vanadium contained in titaniferous magnetite. The grade of the best deposits, at 0.6% V_2O_5, is comparable to the grades of some deposits now being worked in other countries, but it is only slightly more than one third the grade of deposits being mined in the RSA. Vanadium was last produced in Canada in 1990/91 by Carbovan Inc., who recovered the material at the Fort McMurray oil refinery of Suncor Inc. in Saskatchewan during the processing of bituminous sands containing an average of 360 ppm of V_2O_5. The vanadium initially produced consisted of redcake, HVO_3, an intermediate higher-grade product, while the production of vanadium pentoxide was expected to start later on. The plant closed as a result of declining prices and difficulties in marketing this product. Canadian converter Masterloy Products Ltd., a wholly owned subsidiary of Walter Industries Inc. of the United States, produces both ferrovanadium and ferromolybdenum using the aluminothermic process. Canada imports all of its vanadium pentoxide requirements, which in 2001 were sourced mostly from Australia and the RSA. The Canadian ferrovanadium market for its part was supplied by both domestic and imported product from the RSA, China, Austria and the United States. Canada's principal users of ferrovanadium are integrated steel mills, specialty steel companies and mini-mills.

Future potential sources of vanadium in Canada are the Lac Doré, Bell River and Pipestone Lake deposits. All three of these deposits are located in titaniferous-magnetite-rich zones in bedded complexes.

- The **Lac Doré vanadium deposit** located about 70 km southeast of Chibougamau, Quebec, is the most advanced project. The most recent reserve estimate done by owner MacKenzie Bay International Ltd. (MacKenzie Bay) outlined measured and indicated resources of 102 Mt grading 35% magnetite, 17.4% ilmenite and 0.5% V_2O_5. This can be translated into combined proven, indicated and inferred mineable vanadium pentoxide resources of about 2.25 billion kg. In April 2001, the company commissioned SNC Lavalin Inc. to do a feasibility study that was scheduled to be completed by the end of March 2002. SOQUEM INC., a division of SGF Minéral Inc., which is a subsidiary of Société générale de financement du Québec, has the right to acquire a 20% interest in the project upon acceptance of a positive bankable study. If it goes through, MacKenzie Bay plans to develop an open-pit mine and to build a processing plant consisting of primary crushing and stockpiling, ore reclaiming, milling and magnetic separation of concentrate, and roasting and refining of magnetic concentrate. These installations would be complemented by the development of a processing facility with a capacity to produce 63.5 million litres of battery-grade vanadium electrolyte for use in vanadium redox batteries. The initial investment capital cost of the project is estimated at $364 million with a commissioning date set for June 2005.

- The **Bell River vanadium deposit**, also located in northwestern Quebec, is hosted in a bedded complex situated near Matagami. It was discovered in 1997 by Noranda Inc. and is at an early stage of evaluation. Geological resources of up to 200 Mt grading 0.4% V_2O_5 have been estimated at this site.

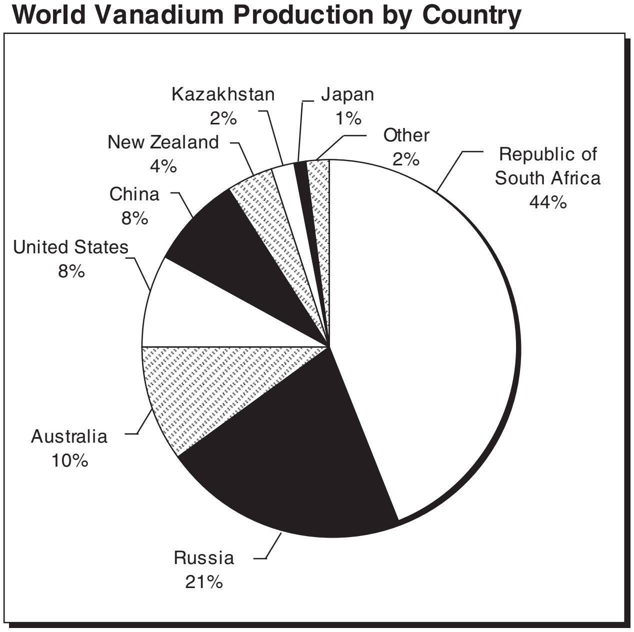
- The **Pipestone Lake deposit** was outlined in 1993 by joint-venture partners Gossan Resources Ltd. (51%) and Cross Lake Mineral Explorations Inc. (49%). Located about 600 km north of Winnipeg, Manitoba, the vanadium-bearing titaniferous-magnetite-rich zones are located in an anorthosite complex. Drill-indicated reserves stand at 40 Mt grading 8.72% TiO_2 and 0.4% V_2O_5, while geological resources are estimated at 685 Mt grading 8.37% TiO_2 and 0.2% V_2O_5.

World Overview

World vanadium production statistics are not officially compiled, which in some ways is one of the root causes of the instability of the industry. However, according to published material, there are two schools of thought. The U.S. Geological Survey estimates total production of vanadium (from all sources) in recent years at about 43 000 t of vanadium content, while the RSA Department of Minerals and Energy estimates this production at about 33 000 t of vanadium content, the difference between the two figures resulting mostly from the double-counting of units. The production is deemed to have increased marginally compared to the previous year. In contrast, world use of vanadium in 2000 is estimated to have increased by as much as 7% along with increased steel production. The production of vanadium pentoxide in the world is restricted to a small number of countries. Based on annual vanadium pentoxide production capacity from all sources, one could venture that the world's production can be split as follows (Figure 2): RSA, 44%; Russia, 21%; Australia, 10%; the United States, 8%; China, 8%; New Zealand, 4%; Kazakhstan, 2%; Japan, 1%; and others, 2%.

- In the **Republic of South Africa**, vanadium occurs in seams of titaniferous magnetite located in the Bushveld Complex, one of the largest bedded mafic intrusives of the world. These seams grade an average of 1.5% V_2O_5 and can be traced on strike for up to 325 km. The RSA's estimated 12.5 Mt of contained vanadium (to a depth of 50 m) represents the world's largest reserves. The country's production of vanadium in 2001 is estimated at 19 000 t of vanadium content. This production comes from four companies: Anglo American's Highveld Steel and Vanadium Corporation Limited (Highveld), Vametco Minerals Corp. (Vametco), Vanadium Technologies (Vantech), and Rhombus Vanadium Holdings Ltd. (Rhovan).

Figure 2
World Vanadium Production by Country



Sources: United States Geological Survey; Department of Minerals & Energy, Republic of South Africa.

Highveld, the largest producer of vanadium in the Western World, significantly reduced production at its facilities in recent years in response to excess capacity in the marketplace. It operates the Mapochs mine in the northeastern province of Mpumalanga where it extracts vanadium-rich titaniferrous magnetite. It also produces vanadium-rich slag and oxides from two plants at its works in Witbank located 110 km from the mine. Slag is recovered from the Highveld steelworks and is processed with ore at the Vantra plant, which has an 8170-t/y (contained vanadium) roasting capacity to produce pentoxide. Most of this material is converted to ferrovanadium on site using both the aluminothermic and electric arc processes. Highveld also produces vanadium trioxide and other derivative vanadium chemicals at its Wapadskloof plant near Middleburg.

Vametco, a subsidiary of **Strategic Minerals Corp. (Stratcor)** of the United States, produces ferrovanadium and the proprietary nitrogen-containing Nitrovan alloys. Because of poor market prices, the company has, over the years, scaled down its vanadium mining operations and switched its feedstock to the use of vanadium-bearing slags from South African steel producers. Its production capacity was last upgraded in 1997 to about 6000 t/y of vanadium content in favour of an increase in Nitrovan alloy production.

Xstrata AG, the Swiss-based mining group – 41% owned by **Glencore International AG** – owns the other two vanadium producers, **Vantech** and **Rhovan**. These two operations supply about 15% of the world's vanadium production and are said to be very low-cost producers. Vantech operates the Kennedy's Vale vanadiferous magnetite mine in Mpumalanga Province and markets both pentoxide and ferrovanadium. The rated capacity of its operation is about 6000 t/y V_2O_5 and 2400 t/y FeV.

The **Rhovan** integrated operation at Ba Magopa mine in the North-West Province produces vanadium pentoxide from vanadiferous magnetite at a rated capacity of about 7000 t/y of V_2O_5. The mining operation, located near Brits in

Bophuthatswana, has proven and probable ore reserves of 90.6 Mt grading 1.97% V_2O_5, down to a depth of 60 m. In 2000, following the shift to export higher-valued vanadium products, Xstrata commissioned a 6000-t/y aluminothermic ferrovanadium facility to convert the V_2O_5 on site. This plant replaced the smaller facility at Vantech.

- **Russia** is reportedly now producing at less than 50% of its installed capacity of around 20 000 t/y of V_2O_5. Production of pentoxide in Russia is mainly from titanomagnetite and ilmenite deposits hosted in bedded mafic intrusive complexes located around Kachkanor and Sverlov in the Ural mountains, and in the Kola peninsula. Vanadium is mined at three main sites: Mount Kachkanar, Gusevogorsk and Pervoural'sk. The ore is converted to pig iron containing about 0.5% V_2O_5 at **the Nizhny Tagil Iron and Steel Works** and the **Chusovskoy Metallurgical Works** and is then further treated, producing slags containing 17-21% V_2O_5. These slags are then processed at the **Tulatchermet** (south of Moscow) and **Chusovskoy** plants to produce 50% and 80% ferrovanadium. The rest is exported to converters such as NIKOM, the Czech Republic-based ferrovanadium producer.

- In **Australia**, the Windimurra mine, commissioned in late 1999 by joint-venture partners **Precious Metals Australia (PMA)** and **Xstrata AG**, is reported to be the world's largest primary producer of vanadium pentoxide. Located near Mount Magnet in the Murchison District of Western Australia, the deposit is made up of vanadiferous magnetite-rich horizons hosted in a lateritic section of the Windimurra bedded mafic intrusive. It has reserves estimated at 106 Mt grading 0.47% V_2O_5. Now sole owner of the project after having acquired PMA's 49% interest in November 2000, Xstrata is reported to be operating Windimurra at close to its designed capacity of 7800 t/y of V_2O_5. In addition to the Windimurra deposit, Australia also has other potential sources of vanadium. These include the **Clough Resources'** Coates Ridge vanadium project near Wundowie in Western Australia, where a vanadiferous-magnetite deposit was mined between 1980 and 1982 but was closed after having delivered just over 300 t of V_2O_5. There is also the Julia Creek oil shale deposit in northeastern Australia's Queensland Province.

- The **United States'** production in 2001 is estimated at slightly less than 4000 t/y of contained vanadium, which came from eight firms primarily located in Arkansas, Louisiana, Texas and Utah. These firms produce a mixture of vanadium pentoxide, ferrovanadium, vanadium chemicals and vanadium metal by processing vanadium-bearing iron slag, fly ash, petroleum residues and spent catalysts. Most of this production is slated for domestic use.

  In late November 2001, led by Strategic Minerals Corp. (the largest U.S. producer of pentoxide) and by Shieldalloy Metallurgical Corp. (the largest U.S. producer of ferrovanadium), The Ferroalloys Association of the United States filed an anti-dumping petition with the U.S. Department of Commerce and the International Trade Commission (ITC) asking for the imposition of anti-dumping duties on imports of ferrovanadium from China and the RSA. The United States already has duties on ferrovanadium imports from Russia ranging from 3.75% to 108% - depending on the producing company - which date back to a 1994 petition. In the present case, the dumping margins estimated by U.S. producers are respectively 49-51% and 66-85%. The ITC made a provisional determination of the case in early January 2002 and is scheduled to announce the final results of its investigation by the end of May 2002. Industry insiders doubt that the imposition of duties will solve the structural problems plaguing the industry, which have resulted in over-production and a slump in prices. However, the imposition of duties would enable U.S. converters to preserve their conversion capabilities and give them some time to adjust to changing market conditions.

- **The People's Republic of China** is reported to be producing vanadium from the mining of titaniferrous magnetite deposits located mainly in the Sichuan and Anhui provinces in central and eastern China, and from slags imported from Russia, the RSA and New Zealand. The largest source, the Panzhihua iron ore mine in Sichuan, is said to host reserves estimated at 1.2 billion t grading 33.2% Fe_2O_3, 11.6% TiO_2 and 0.3% V_2O_5. Vanadiferous slags are also recovered from the Maanshaan Complex in the Anhui Province and from iron works in the Hubei and Chengde provinces. These slags are processed at seven plants for the production of vanadium pentoxide (total capacity of 8500 t/y V content), four of which have facilities to convert the material into ferrovanadium (total capacity of 4000 t/y V content).

- In **Japan**, falling ferrovanadium prices resulted in the October 2001 closure of the Uji plant, owned by Awamura Metal Industry Co., Ltd. (a subsidiary of Mitsui Co., Ltd.), and the August 2001 announcement by Nippon Denko of the transfer of its production at the Toyama plant to a joint-venture project with Highveld in the RSA.

PRICES

Historically, vanadium pentoxide prices have remained fairly stable except for two fairly recent price surges (Figure 3). The first one occurred between the last quarter of 1988 and the third quarter of 1990 while the second surge happened nearly 10 years later between early 1997 and the last quarter of 1998 with a peak in February 1998. The first surge resulted from a major increase in demand for ferrovanadium by the steel and aerospace industries while the second resulted from a tightening of supplies due to the process conversion of Russian suppliers. Owing to oversupplied markets, prices gradually slipped after the 1998 peak and are now testing historical lows (Figure 4). The entry of new capacity onto the market, such as Australia's Windimurra, exacerbated matters and forced the introduction of a price war. Prices for U.S. free market vanadium pentoxide stabilized in late 2000/early 2001 at a level of US$1.35-$1.40/lb V_2O_5, firmed up to reach a high of US$1.50/lb V_2O_5 in mid-April 2001, and then continued their slide to close the year at around US$1.10/lb V_2O_5.

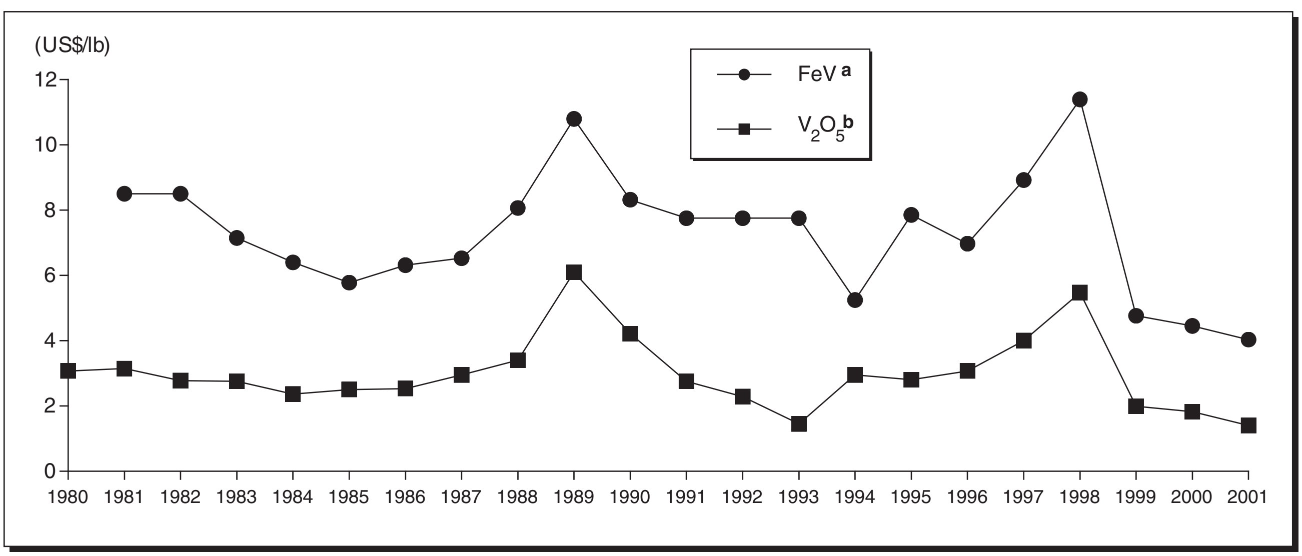
During the same period, ferrovanadium prices moved in a similar fashion. Free market ferrovanadium prices started the year in the range of US$3.85-$4.00/lb vanadium content for 80% V, reached a peak in the range of US$4.00-$4.50/lb in the second quarter of the year, and slid thereafter to finish the year at US$3.60-$3.80/lb.

OUTLOOK

The introduction by the United States of preliminary anti-dumping duties on imports of ferrovanadium from China and South Africa, as well as similar duties already in place on imports from Russia into the United States, increasing use in North America as it comes out of recession, and expected production cutbacks will help stabilize the market. However, the introduction of duties by the United States is not expected to resolve the basic market imbalance caused by the excess capacity in ferrovanadium production brought about by pentoxide producers aiming to market value-added products. In the short term, the duties will give the U.S. producers a bit of time to adjust to changing market conditions but the long-term trend we are witnessing, which is the availability of vanadium products at low prices, should eventually result in the closure of higher-cost capacity. A case in point is the recent closure of some of Japan's ferrovanadium capacity.

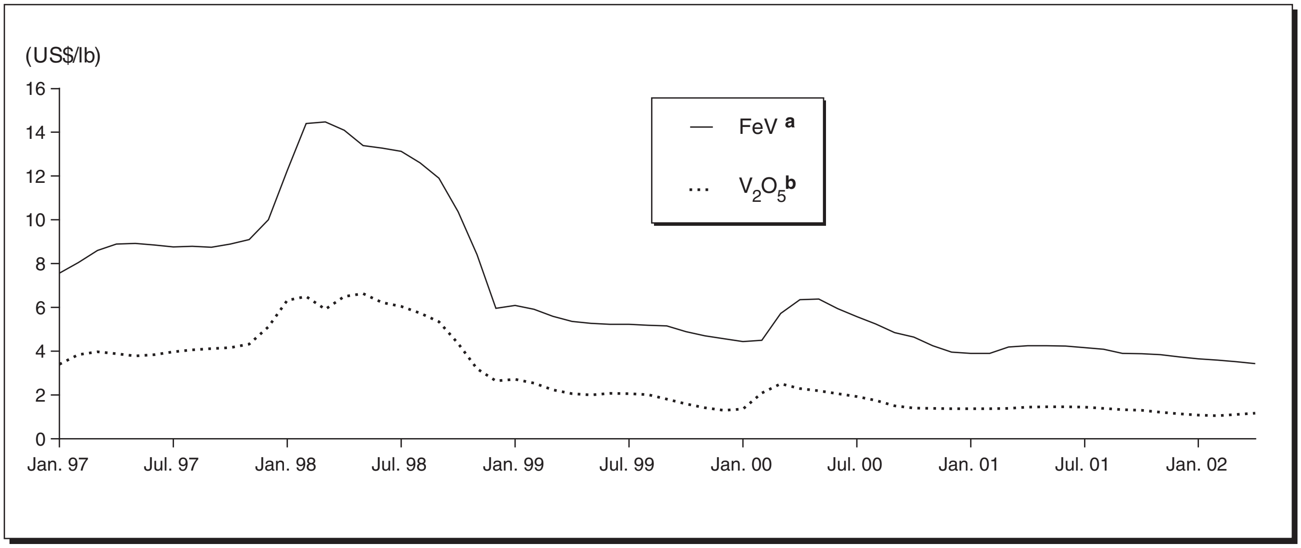
In the short and medium terms, the use of vanadium products is expected to increase further as a result of greater industrial activity in the recovering world economies and because of increasing use of vanadium per unit of steel in Asia, particularly in China, which is the world's fastest growing economy. Growth should centre around the steadily expanding steel industry, especially for structural shapes, tool steels, and automobile components. However, the recognition by markets of the potential use of vanadium in

Figure 3
Vanadium Products Price Variations, 1980-2001



Sources: *Metal Bulletin*, United States Geological Survey.
[a] Annual average price per pound of contained vanadium, U.S. producer. [b] Annual average price per pound V_2O_5, free market.

Figure 4
Vanadium Products Price Variations, 1997-2002



Source: *Metal Bulletin*.
[a] Price per pound of contained vanadium, U.S. free market 70-80% V in warehouse, Pittsburgh. [b] Price per pound V_2O_5, Europe, min. 98%.

redox batteries, as a convenient energy storage system, may create significant growth prospects for the industry over the short to medium term with corresponding pressure on prices. As in the past, the substitution of ferrovanadium by ferroniobium could start to take place in some applications if prices increase too much.

Notes: (1) For definitions and valuation of mineral production, shipments and trade, please refer to Chapter 64. (2) Information in this review was current as of January 31, 2002. (3) This and other reviews, including previous editions, are available on the Internet at www.nrcan.gc.ca/mms/cmy/index_e.html.

NOTE TO READERS

TARIFFS

Item No.	Description	Canada MFN	Canada GPT	Canada USA	United Canada	E.U. MFN	Japan (1) MFN
2825.30	Vanadium oxides and hydroxides	Free	Free	Free	Free	5.5%	Free
7202.92	Ferro-vanadium	2.5-6.5%	Free-5%	Free	Free	2.7%	2.5%

Sources: *Customs Tariff*, effective January 2002, Canada Customs and Revenue Agency; *Harmonized Tariff Schedule of the United States*, 2002; *Worldtariff Guidebook on Customs Tariff Schedules of Import Duties for European Union* (41st Annual Edition: 2001); *Customs Tariff Schedules of Import Duties for Japan* (35th Annual Edition: 2001).
(1) GATT rate is shown; lower tariff rates may apply circumstantially.

TABLE 1. CANADA, VANADIUM IMPORTS AND EXPORTS, 1999-2001

Item No.		1999		2000		2001 (p)	
		(tonnes)	($000)	(tonnes)	($000)	(tonnes)	($000)
EXPORTS							
2825.30	Vanadium oxides and hydroxides						
	United States	1	21	–	–	–	–
	Total	1	21	–	–	–	–
7202.92	Ferrovanadium						
	United States	564	9 276	388	4 578	304	2 984
	Trindad and Tobago	4	130	–	–	–	–
	Total	568	9 406	388	4 578	304	2 984
IMPORTS							
2825.30	Vanadium oxides and hydroxides						
	Australia	–	–	24	383	318	4 724
	South Africa	1 259	10 226	638	6 347	135	1 674
	United States	49	652	24	381	40	617
	Germany	. . .	6	1	35	4	80
	Other countries	–	4	1	15	8	146
	Total	1 308	10 888	688	7 161	505	7 241
7202.92	Ferrovanadium						
	Austria	33	415	65	747	39	552
	United States	213	3 525	154	2 260	49	618
	South Africa	303	4 344	287	3 718	324	3 226
	China	5	62	5	53	100	1 049
	Other countries	143	2 109	88	1 145	44	485
	Total	697	10 455	599	7 923	556	5 930

Source: Statistics Canada.
– Nil; . . . Amount too small to be expressed; (p) Preliminary.
Note: Numbers may not add to totals due to rounding.