COMMODITY REPORT

Vanadium – sources, appplications and markets

by Per Storm

Vanadium plays an important role as an alloying element in several types of steel. It is an irreplaceable component in High Strength Low Alloyed steel (HSLA). In this paper, Per Storm offers his interpretation of the essence of the industry. In doing so, vanadium sources, applications and markets are a fundamental part. However, the focus of the paper is the vanadium production chain, from mining to application.

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Although the use of vanadium has been growing steadily over the last decades and although the vanadium price reached historically high prices during the last decade, the industry has not been one of abundant profits. On the contrary it has been experiencing an almost continuous depression during the same time. Here, I will discuss some causes of this seemingly paradoxical situation.

Vanadium mining is a highly concentrated industry. Since only a few countries mine vanadium, it has, for some time, been regarded as a strategic resource.

Although it is questionable whether vanadium is strategic or not (see below), it is clear that the recent political development will influence the future of the vanadium market(s) and – most probably – affect both technology and economy of this minor but noble[1] alloying metal.

In general, the statistics are reproduced from the latest available figures. Notes on the state of affairs (production, works in operation, trade etc.) in economies in transition, such as the former USSR, are not updated to present status (1994) in all cases (due to the non-occurrence of such statistics). They are rather to be regarded as historical estimates or ideal capacity figures.

History

Vanadium was discovered in 1830 by the Swedish scientist Nils Sefström[2] who found the substance when investigating brittleness in iron. As he treated the iron with acid, he noted that iron from ore mined at Smålands Taberg, produced a black powder, apart from the regular findings.

After testing the powder for the presence of known substances such as chromium and uranium, Sefström concluded that what he had found was a hitherto unidentified body. He was able to identify the substance as a new metal which he named after the Nordic goddess of beauty: Vanadis.

In the early 1920s the Swedish metallurgist Rutger von Seth[3] published an extensive work on vanadium. In his writings, he accounted for the location of known vanadium-bearing ores, their performance in the blast furnace and steel making processes and he described a new method to beneficiate vanadium. von Seth found that vanadium and silicon were oxidized to an acid slag during the first minutes of the blow in the Bessemer process. He therefore proposed and patented a method for recovery of vanadium from hot metal. To create a slag with a high content of vanadium, the vanadium bearing hot metal should be pre-blown at a comparatively low temperature in an acid lined vessel. In subsequent experiments, a slag of barely ten weight per cent vanadium pentoxide was obtained. Vanadium containing slag of the von Seth-type proved itself to be an excellent raw material for the production of vanadium pentoxide and ferrovanadium. The process was put to industrial use and was further developed by Christiania Spigerverk in Norway and by Domnarfvets Jernverk in Sweden. In a developed form, von Seth's method is still used to produce vanadium rich slags in some countries.

Production and consumption

In pure form, vanadium is a greyish metal which is rather common in the earth's crust (135 ppm, compare e.g. copper 35 ppm or lead 13 ppm). However, since it seldom occurs in large concentrations it is rarely beneficiated as a principal product. Producers of vanadium fall into two main categories: Those producing vanadium as a by-product from iron (as hot metal), uranium or phosphates, and those recovering vanadium from different types of residues (e.g. crude oil, tar sands, spent catalysts, slag or fly ashes from oil fired power utilities). Some producers also combine the two. Today, vanadium is not produced as a principal or sole product.

Vanadium in a nutshell

Vanadium (V) is a greyish metal which is rather common in the earth's crust, although, seldom in high concentrations. Vanadium has its greatest application as a carbide former in HSLA (High Strength, Low Alloy steel) and tool steel, mainly added as ferrovanadium (FeV, commonly 80 per cent V and 20 per cent iron).

Vanadium is generally beneficiated to a rich slag from titanomagnetite hot metal. Ferrovanadium, is produced by metallothermically converting vanadium pentoxide (V_2O_5) from a hydrometallurgical treatment of slag. All these vanadium products (slag, pentoxide and ferrovanadium) are also traded.

Highveld Steel & Vanadium is the largest producer but substantial slag production is also carried out by producers in (the former) USSR and China. Downstream, the markets become more competitive. The main semi-finished product, pentoxide, is largely sold to and converted in industrialized countries. Applications of ferrovanadium as an alloying element is largely carried out in steel mills in the OECD area (USA is the largest single consumer), particularly in countries with a tradition of special steel making such as speed steel or tool steel. Accordingly, it is fair to call vanadium a high tech steel additive.

Vanadium used to be considered a strategic metal (from an OECD perspective) but due to recent development it seems to be moving away from that description.

Prices on vanadium have been low during the last decade apart from a price rally in the late 1980:s. However, closing of several operating units may be a long time structural effort and the price may turn up again. On the other hand, several new ventures have been planned and if they are put on stream, the development of the vanadium price may be continuing down.

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The availability of different vanadium raw materials – as well as metals and minerals in general – were earlier assessed with a five-year interval by the United States Bureau of Mines (USBM). In the latest available assessment[4], the total reserves of vanadium were estimated to 4.8 Mt and the reserve base to 18.3 Mt. More recent figures presented in Minerals Handbook[5] offer an estimate of the reserve base of 16.6 Mt and the reserves of 4.3 Mt. The latter source also estimated the identified resources to 63 Mt. At the present consumption rate, the reserve base will last for more than 200 years. However, vanadium-containing carbonitic shales (where vanadium is abundant but in a very low concentration) and petroleum ashes were not included in this assessment. The Minerals Handbook estimates the static reserve life to 135 years. A geographic division of the estimates is shown in table 1.

Today, the main route to produce vanadium is to beneficiate it from vanadium-bearing iron ore. An overview of the iron-based production route is illustrated in figure 1. In this case, the ore is smelted in a blast furnace or in a sub-

Table 1. Estimate of the world reserves and reserve base of vanadium in thousand tonnes of vanadium content

Geografic area	Reserves 1985		Reserves 1990		Reserve base 1985[2]	
	kt	%	kt	%	kt	%
North America	185	4.0	135	3.2	2 500	13.7
South America	25	0.5	n.a.	n.a.	130	0.7
USSR[1]	2 900	60.4	2 631	61.7	4 500	24.6
South Africa[1]	950	19.7	862	20.2	8 600	47.0
China[1]	670	14.0	500	14.2	1800	9.8
Pacific	35	3.1	30	0.7	570	3.1
Total	**4 800**	**100**	**4 267**	**100**	**18 300**	**100**

1. Apart for minor deposits in Europe (except USSR), Africa (except South Africa) and Asia (except China); 2. The reserve base was estimated to 16.6 million tonnes in 1990, 70 % of this in USSR and south Africa.
Source: (1985) U.S. Bureau of Mines; (1990) Minerals Handbook.

Figure 1. Vanadium production from ore

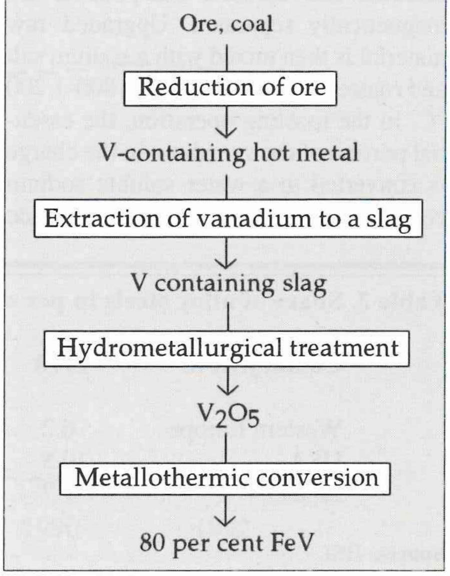


Table 2. World production of vanadium-containing commodities by country. Tonnes of vanadium content.

Countries	1985[1]	1986[1]	1987[1]	1988[1]	1989	1990	1991	1992	1993[1]
China[2]	5 000	5 000	5 000	5 000	4 500	4 500	4 500	4 500	4 500
Finland	2 350	—	—	—	—	—	—	—	—
South Africa[3]	15 449	16 930	15 715	18 060	16 500	17 000	15 500	14 300	14 600
USSR[2]	10 500	10 500	10 600	10 600	9 600	9 600	8 000	6 000	7 200
USA total	3 695	3 330	3 508	3 252	n.a.	n.a.	5 600	5 300	5 000
from ore[4]	*1 000*	*1 000*	*1 000*	*1 000*	*1 200*	*500*	*100*	*1 000*	—
from catalysts and ashes	*2 695*	*2 330*	*2508*	*2 252*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Japan[5]	840	929	925	925	n.a.	n.a.	600	800	n.a.
New Zealand	—	—	—	—	—	—	2 200	1 700	n.a.
Grand total	**37 800**	**36 700**	**35 750**	**37 900**	**31 600**	**31 600**	**35 800**	**33 200**	**35 000**

1. Short tons of vanadium content; 2. Estimated; 3. South Africa: roughly 40 per cent is pentoxide and vanadate products and 60% is vanadiferrous slag products; 4. Actual figure withheld for propriety reasons; 5. Spent catalyst and petroleum ashes; n.a.: not available.

Source: (1985 - 1988) U.S. bureau of Mines; (1989 - 1990) Minerals Handbook; (1991 - 1993) Raw Materials Data.

merged arc furnace depending on ore composition. Vanadium is separated from the liquid hot metal in a treatment operation were it is oxidized and beneficiated to a slag. The slag is separated from the liquid metal and solidified. In a following step, the slag is mixed with other ores (other than iron ores), clays, shales or other residues. The mix is comminuted and metallic components are magnetically separated. Upgraded raw material is then mixed with a sodium salt and roasted at temperatures of 800-1 200 °C. In the roasting operation, the essential portion of the vanadium in the charge is converted to a water soluble sodium compound, $NaVO_3$. A few high grade vanadium-bearing iron ores (> 2 per cent V) may be comminuted and roasted directly. After dissolving $NaVO_3$ in water, possible impurities (mainly phosphorus) are precipitated. Following the precipitation, the pH of the solution is adjusted to precipitate a vanadium oxide containing product (ammonium metavanadate or ammonium hexavanadate). The vanadate is subsequently calcined to form vanadium pentoxide V_2O_5 or vanadium trioxide V_2O_3. The oxides are dried and melted to obtain suitable conditions for a subsequent reduction to ferrovanadium. Said reduction is usually carried out aluminothermically, but a silicothermic practice is sometimes employed.[6]

Table 3. Share of alloy steels in per cent of total output.

Country/Area	1970	1980	1985
Western Europe	6.2	12.3	12.9
USA	10.5	14.9	13.9
Japan	9.7	12.6	16.9

Source: IISI.

The world primary production of vanadium-containing ore (from which vanadium commodities are produced) is highly geographically concentrated. Five countries, all but two outside the OECD-area, account for all production; see table 2. In the United States, the vanadium pentoxide production from indigenous ore can be estimated to less than 1 000 t. New Zealand is the only newcomer among the primary producers in recent years. This means that roughly 80 per cent of the total production of primary vanadium is carried out outside the OECD countries. It is important to note that the capacity and production figures presented in the table are not equivalent to what is supplied to the market as high grade ferrovanadium. Supplied volumes are generally different to production of pentoxide due to stockholding and losses when the pentoxide is converted into ferrovanadium.

There are no available production figures regarding the actual production in Chile during the 1980:s, although vanadium-rich iron ore is mined there (roughly 2 500 tonnes of vanadium every year). Accordingly, the country has at least resources to produce large amounts of slag. Production of ferrovanadium in Japan is generally based on used catalysts (since recycling of these are possible) and fly ashes from oil power utilities. Available figures indicate that Japan mainly imports ashes and residues but is probably also a large importer of "pure" pentoxide.

Figures of production, capacity and consumption vary from source to source. However, it can be concluded that the vanadium production during the last years was in the vicinity of 35 000 tonnes per year[7]. The production capacity – working and mothballed – is in the vicinity of 50 000 tonnes (see e.g. Minerals Handbook 1993). If the rated capacity is estimated to 10 - 20 per cent larger than working capacity, this would entail a 70 - 80 per cent degree of utilization during the last years. In the beginning of the 1990s, there were plans for large capacity increases and new ventures, mainly in South Africa.[8]

If these plans are put into operation, there would most likely be a large overcapacity present during the rest of the 90's.

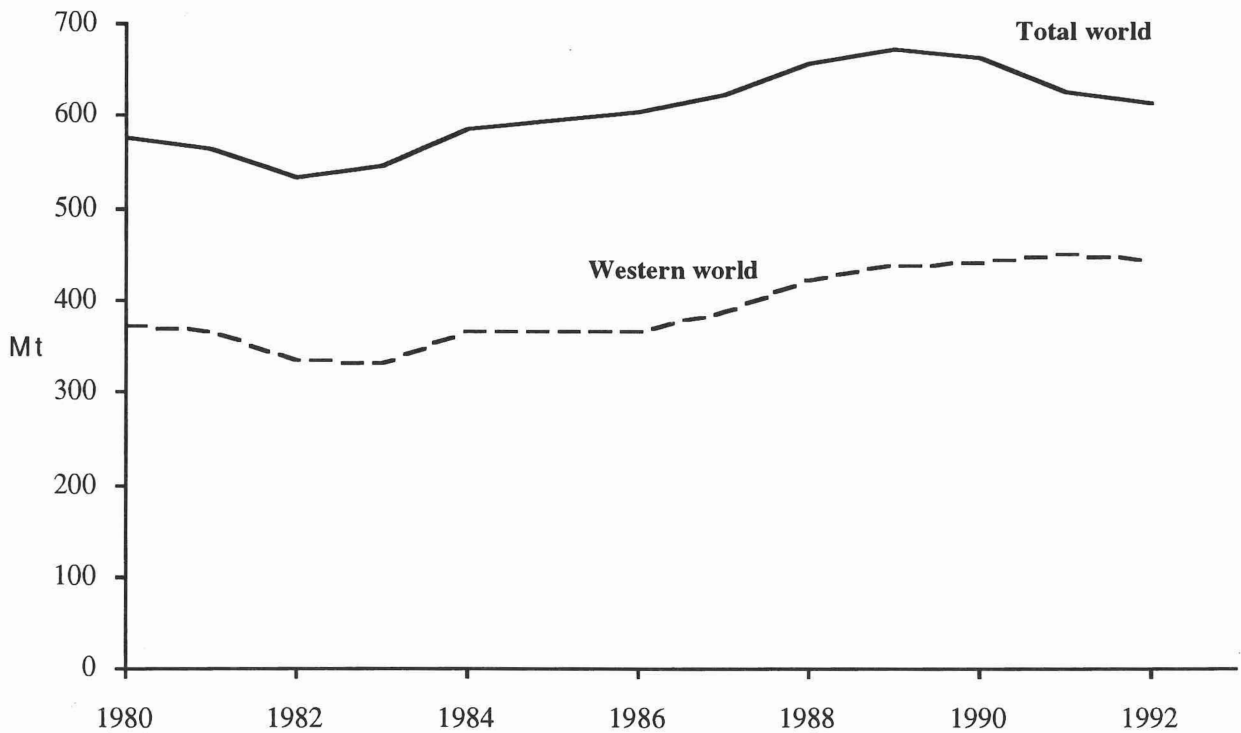
More then 90 per cent of all vanadium consumed is added to steel as an alloy.

Table 4. Consumption of vanadium (tonnes V) 1969 to 1989

Country/Area	**1969**		**1979**		**1989**	
	t	**per cent**	**t**	**per cent**	**t**	**per cent**
Western Europe	6 200	32	8 070	27	7 958	34
Eastern Europe	2 220	11	3 530	12	1 980	9
USSR	1 770	9	5 450	18	1 000	4
USA	7 240	37	7 760	26	6 100	26
Japan	1 470	8	3 230	11	2 982	13
Others	560	3	1 660	6	3 362	14
Total	**19 460**	**100**	**29 700**	**100**	**23 382**	**100**

Source: (1969, 1979) Eggert et al. [Metal, 12/1981]; (1989) GfE [1990]

Figure 2. Apparent world consumption of finished steel 1980 – 1990



Source: IISI.

Accordingly, the development in the steel markets is of vital importance to the consumption of vanadium. During the 1980s there has been no significant growth in the apparent steel consumption in the industrialized countries, see figure 2. However, the consumption of alloyed steel increased somewhat between 1970 and 1985, see table 3. Alas, no recent figures have been compiled. However, it is likely that this growth has continued.

As a result, the consumption of vanadium rose during the 1970s and has been stable during the 1980s (at least in the OECD area); see table 4. As can be seen, most of the vanadium is consumed in the industrialized countries. The slight downturn in vanadium consumption from 1979 to 1989 may be attributed to the slump in metal consumption in the former centrally planned economies. For example, in the (former) USSR consumption declined from 18 per cent of world consumption in 1979 to 4 per cent in 1989. However, these figures must be taken with a grain of salt. Consumption figures of the centrally planned economies (both formerly and present) are difficult to obtain. Moreover, some of the economies in transition have not yet statistics available for detailed information of such matters, nor always the will to present them. However, in the later part of the 1980s, the (former) USSR was estimated[9] to consume some 4 500 tonnes each year. The consumption in China was assumed to be negligible.[10] In the latter case, it is likely that the vanadium consumption will increase since the Chinese steel production is rapidly approaching 100 Mt per year.[11]

Of the individual countries, USA is the largest consumer although Western Europe is larger taken as a whole. In Western Europe, Germany is by far the largest consumer with 43 per cent of the total consumption. Scandinavia is the second largest consumer in this region using 14 per cent of the vanadium. In this region, Sweden is probably the largest consumer, being a large producer of high alloyed steel. France, Italy and the United Kingdom each contribute with 10 per cent of the consumption in Western Europe[12]. It is interesting to note that Japan consumes less than half as much vanadium as the US although Japan consumed as much steel as USA. This, among other things, indicates a different structure of steel products between the two countries.

Application

Over the last thirty years there has been a tremendous development to increase the strength in low alloyed construction steel. In the beginning, these types of steel were generally classified according to their strength and carbon content (roughly 0.3 per cent). When welding became more common, the carbon content had to be reduced. The ductility and the transition temperature between brittle and ductile raptures came into focus. The first upgrading step was to use aluminium as a grain refiner in combination with nitrogen. When precipitation hardening was introduced, an increasing tensile strength was obtained. Today, modulus of 1100 MN/m^2 and transition temperatures down to -80 °C are common for HSLA steel, compared to modulus of roughly 220 and transitions temperatures of 0 °C for ordinary construction steel such as Fe 360C (equals roughly EN 10025-S235JRG2 or ASTM A36).

Presently, vanadium is added to several types of steel such as microalloyed steel (HSLA-steel), tool steels and cutting steels. Accordingly, if the market for alloyed steel grows, so will the market for vanadium, linking development of vanadium to the general steel development. In the early sixties, vanadium was mainly used in high-speed steel and miscellaneous low alloyed steel. Later, low alloyed steel, HSLA-steel and full-alloyed steel became more prominent. At present, and probably in the future, steel with less than 0.1 per cent vanadium will become more important for the vanadium consumption, than steel containing a higher content, mainly due to the large quantities involved. Most relevant for the use of vanadium are: tubular goods used in oil producing applications (other than pipelines) followed by pipeline steel, structural steels, tool and high speed steels. A comprehensive classification is presented by Hess & Sattelberger[13]; see table 5. However, the types of steel where the specific properties of vana-

Table 5. Fields of Application for Vanadium in 1987

Use	Consumption
HSLA-steel	33.85
Other full alloyed steel	24.01
Carbon steel	19.24
Tool steel	10.39
Stainless and heat resistant steels	0.73
Non-ferrous alloys	8.73
Cast iron	0.79
Superalloys	0.69
Welding and hard-facing materials	0.16
Catalytic uses	0.95
Miscellaneous and unspecified	0.56
Total	**100.00**

Source: Hess & Sattelberger, 1989

Table 6. Mines producing vanadium-containing ore for vanadium commodity production 1991

Country	Company	Mine	Ore
Chile	Comp. Mineira del Pacifico SA	El Romeral, Coquimbo	Titanoferrous magnetite
China	State owned	Panzihua, Sichuan	"
	"	Chendge, Hebei	"
	"	Maanshan, Anhui	"
New Zealand	New Zealand Steel	n.a.	Vanadiferrous sand
USSR	State owned	Kachkanar 1&2	Titanoferrous magnetite
	"	Pervouralsk	"
	"	Jekaterinaburg	"
	"	Kusa, Chelyabinsk	"
	"	Lisakovsk, Kazak.	Oolotic Göthite
South Africa	Highveld Steel & Vanadium Corp	Mapochs, Transvaal	Titanoferrous magnetite
	Transvaal Alloys Pty Ltd	Uitvlug, Transvaal	"
	Vametco	Uitvalgrond, Transvaal	"
	Vametco	Krokodilkraal, Transvaal	"
USA	JR Simplot Co	Gay, Idaho	Phosphate rock
	Monsanto Ind. Chem. Co	Henry, Idaho	"
	White Mesa Mill[1,3]	Colorado plateau	Carnotite ore
	Umetco[1]	Colorado plateau	"
	Stractor[3]	Wilson Springs, Ark.	Vanadiuferrous clays

1. Mothballed at present; 2. Operates only at high pentoxide prices. 3. Co-owned by Union Carbide Corp and Energy Fuels Nuclear Inc
Source: U.S. Bureau of Mines, updated by the author, last entry 1991.

dium are most prominent are more highly alloyed steel grades such as tool steel.

The effect of the micro-alloying elements in HSLA steel is based on their affinity to elements such as carbon, nitrogen and oxygen. Of ordinary alloying metals, only tantalum and niobium have higher affinities to carbon than vanadium. Vanadium's affinity to nitrogen is higher then for manganese, chromium, tungsten and silicon but less than for aluminium. Vanadium and aluminium are for that reason often used together, creating a precipitation hardening using the grain refinement effects of the aluminium-nitrides and vanadium's higher affinity to carbon. In general, vanadium has little effect on grain refinement compared to e.g. niobium. Compared to ordinary deoxidizers, vanadium has a lower affinity to oxygen.

As said, the characteristics of vanadium, i.e. how it affects the mechanical properties of steel are most prominent in high alloyed steel such as tool steel. A tool steel is used for the manufacture of tools for cutting, forming or shaping. The earliest tool steels were carbon steels but, during this century, highly alloyed tool steels have come to dominate. Steel alloyed with relatively large amounts of tungsten, molybdenum, manganese, vanadium, and chromium is capable of withstanding severe operating conditions. During operation, most tools must withstand a high shock load without breaking or undergoing excessive wear of deformation, often during high temperatures. No single material combines maximum levels of toughness, resistance to wear, and resistance to softening. Most tools are wrought products, although powder metallurgy has become more important in recent years. The alloys are melted in small-tonnage electric-arc furnaces, and all heat treatments must be conducted in protective atmospheres to avoid decarburization. The effect of vanadium in tool steels can be summarized as follows:

- small additions improve hardness during high temperatures and reduce grain growth,

- improve the cutting properties,
- is a strong carbide former, thus creating hard phases (in e.g. surfaces)
- increases the tensile strength and yield point, and
- produce synergistic effects with tungsten in highspeed tools.

Vanadium is little used in stainless steel today. Since the stainless market has been one of impressive growth, it is interesting to examine the possibilities of using vanadium in such products. Kawasaki Steel in Japan has, for example, modified the type 316LN stainless steel (low carbon and nitrogen content) by adding 1 per cent of vanadium. The major application of this alloy is in cryogenics. Addition of vanadium to austenitic stainless steel (e.g. kitchen sinks) is limited by its strong ferrite-forming tendency. This is one of the reasons why vanadium is seldom used in stainless steel. However, large amounts can be added to ferritic stainless steel (e.g. tableware), since the solubility of vanadium in ferrite is (practically) unlimited. Vanadium improves the impact toughness of ferritic stainless steel which, inherently has poor toughness especially in weldments.[14]

To enhance the use of vanadium in the steel industry, a vanadium development organisation (VANITEC) was formed in 1972. During the 1970s, the development of the HSLA-steel grades was in focus. In recent years, however, the focus has shifted to more fundamental research.

There has also been a change in the qualities in which vanadium is added to steel. In the beginning of the 1980s, ferrovanadium containing 40 or 60 per cent vanadium, as well as high carbon vanadium alloys, were common. Since the end of the 1980s, almost exclusively highgrade (80 per cent V) ferrovanadium is used. The same trend can be found in for example ferromanganese where high grade electrolytic manganese is increasing its market share compared to conventional ferromanganese.

Markets and trade

Figures on primary output were presented in table 2. However, in most countries individual companies actually control the mining – although sometimes government owned. Mining companies producing vanadium are shown in table 6. It should be noted that during the last years several US mines been mothballed due to low prices of the main product. For example, both carnotite miners (uranium ore) on the Colorado plateau, Umetco and Energy Fuels Nuclear have closed their operations.[15] As a consequence, only two US mines were in operation in 1991. However, Stratcor only operates its Wilson Springs vanadiferrous clay mine at favourable pentoxide prices.

These producers mainly produce a semi-finished product such as vanadium containing slag or pentoxide. The producers of the applicable product, ferrovanadium, are presented in table 7. In the table, rough capacity and output figures are also presented. A few comments are necessary regarding the table. Apart from the companies presented in table 6 and 7, a few others are active as vanadium commodity producers. Vanadium Technology of South Africa (50/50 owned by Kiln AG of Switzerland and Vantech AG of Liechtenstein) are not found in either of the tables. However, it is active in the vanadium market, either as a pure pentoxide producer (from purchased slag) or a convertor to ferrovanadium although not on a permanent basis. It is also likely that Transvaal Alloys (owned 35 per cent each of Metallgesellschaft in Germany and MIM Holdings of Australia and 30 per cent by Degussa in Germany) converts some of its raw material (mined) to either pentoxide or ferrovanadium.

In table 7, the capacity of one of the Brazilian producers is only theoretical, that is, the total capacity of Ferrotitanium, Ferromolybdenum, Ferrovanadium and Ferrotungsten together on a full year production scale. Total Chinese production cannot be separated on the individual works. According to Chinese information[16] the works presented in the table are the only works producing ferrovanadium in China. Some figures are – of course – approximate but most have been checked individually which means that the deviation should be small.

As can be concluded from tables 6 and 7, the only fully integrated company of any importance is Highveld Steel & Vanadium Company of South Africa. It is by far the most important player in the vanadium market. It is owned by one of the major mining conglomerates of the world, the Anglo American Corporation of South Africa. Highveld had a profitable decade during the 1980s with pretax profit rising from 36.0 million South African Rand (MZAR) in 1983 to 566.0 MZAR in 1989.[17] However, in 1990 the pretax profit was more than cut into half to 201.0 MZAR due to a slipping market and low prices through out the year.

Apart from Anglo American, the large ferroalloy producers Metallurg Inc. (through its subsidiaries GfE and Shieldalloy) and the Société Générale de Belgique (through its subsidiary SADACI) are important participants in the market. The largest independent producers are the Austrian Treibacher Chemische Werke and the US Stratcor, which is a semi-integrated company with its own mining facilities. Together, these companies control almost two-thirds of the output to the ferrovanadium market.

During the 1980s, the vanadium industry has been almost constantly depressed. The number of ferrovanadium producers has been cut in half. In the beginning of the decade, almost 50 were in operation but in 1990, only 25 were active.[18] In all the major production and consumption areas, such as USA, Western Europe and Japan, the number of producers has diminished.

The decline has been most apparent in the United States. Notwithstanding the large reduction of producers, most of the surviving companies have for a long time operated on a 50 - 60 per cent utilization

Table 7. Main ferrovanadium producers in the world. Output, capacity (in tonnes V) and ownership 1990.

Country	Company	Output	Capacity	Ownership
Argentina	Pamet	n.a.	n.a.	n.a.
	Stein Ferroalleacianes Sacifa	n.a.	n.a.	n.a.
Austria	Triebacher Chemische Werke	3 000	3 500[1]	private
Belgium	SADACI NV	3 500	3 500	Soc. Gen. Belgique
Brazil	Termoligas Metalurgicas SA	240	400	private
	Cia Paulista de Ferro Ligas	25	1 200[2]	Salles Leite
Canada	Masteralloy Products Inc	1 400	1 400	AIMCOR USA
China	Erme Ferroalloy Plant[3]	2 900	n.a.	State-owned
	Nanjing Ferroalloy Plant	n.a.	n.a.	State-owned
Germany	Gesellschaft für Elektro-metallurgi, GfE	4 500	5 000[1]	Metallurg Inc
Hungary	Ötvözetgyar	130	200[1]	State-owned
	Hungaraloy	150	200[1]	private
Japan	Awamura Metal Industry Co. Ltd	575	800	private
	Taiyo Mining and Industrial Co.	2 000	2 000[1]	private
	NKK Corp	150	200[1]	NKK Corp
Mexico	Ferroaleaciones de Mexico, FERROMEX	n.a.	150[1]	n.a.
	Ferralver SA	n.a.	n.a.	n.a.
USSR	Chusovskoy Metallurgichemiskiy Kombinat	n.a.	n.a.	State-owned
	Tulachermet Kombinat	n.a.	n.a.	State-owned
		1 100	1 100	State-owned
Spain	Ferroaleaciones Especiales Asturianas			
South Africa	Highveld Steel and Vanadium Corp Ltd	200	500	Ferromet
	Vametco	2 800	2 800	Anglo Am. Corp
	Ferroalloys and Metals Ltd	200	500	Stratcor
UK	BEAR Metallurgical Corp.	800	>2000	Neepsend PLC
USA	Shieldalloy Corp.	1 700	2 000	private
	Strategic Metal Corp, Stratcor	1 500	2 700	Metallurg Inc
				private
Total in available figures		**26 870**	**29 000**	

1. Approximately 2. Theoretical capacity 3. Total Chinese production.
Source: Metal Bulletin, updated by the author.

ratio (at least during the beginning of the 1990s).[19]

Accordingly, overcapacity has been undisputable. However, this state of affairs may not be blamed on rigorous government regulations or subsidised production. In fact, the state-owned influence in the ferrovanadium industry is not as important as in other ferroalloys. The (formerly) centrally planned economies have not reported any major amounts of ferrovanadium production. In the production chain, the (former) USSR and China are mainly active as slag exporters. Of the newly industrialized countries (NIC), it is noteworthy that none of the Asian "four tigers" are present although all of them are increasingly important steel producers. The NIC group is represented by Chile as a mining country and Argentina and Brazil as ferrovanadium producers, although none of them on any significant scale. There are no Third World countries present in the vanadium business today. Thus, it would be fair to label vanadium is a high-tech additive to steel.

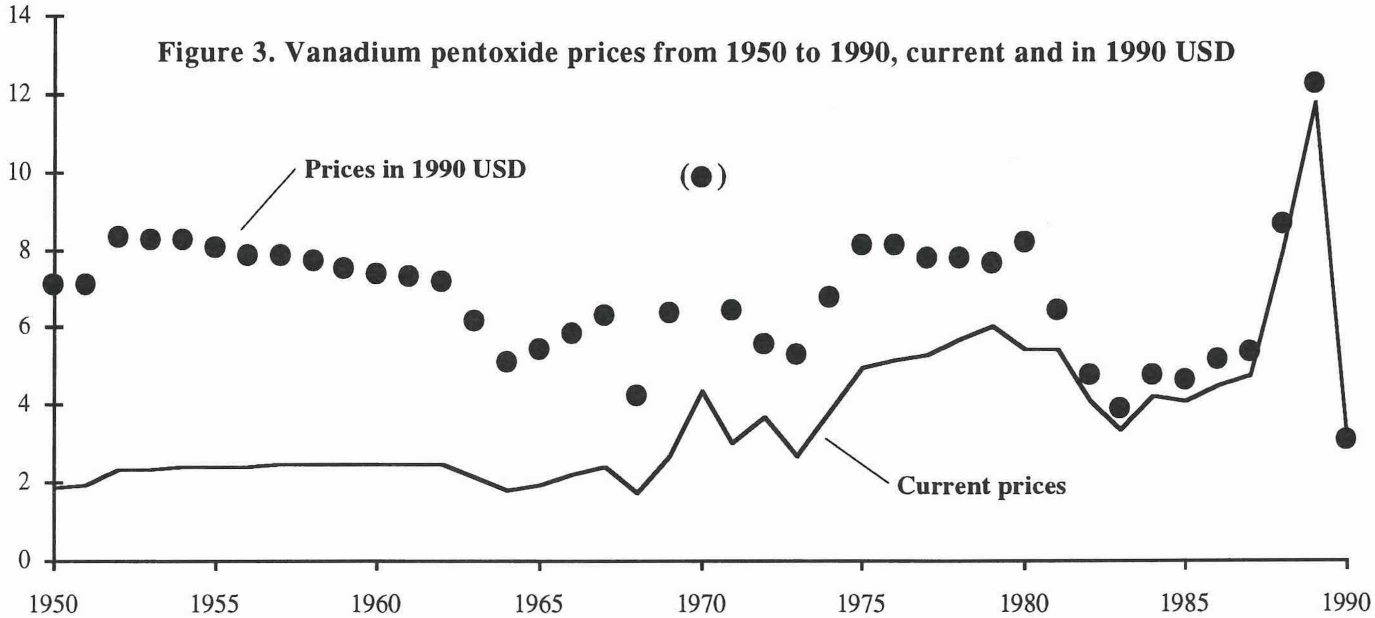
Markets

As can be expected from the production technology, three types of vanadium commodities are traded: Vanadium- containing slag, V_2O_5 and high grade ferrovanadium (as 80 per cent V FeV).[20] No open, free market, quotations are made for vanadium slag since it is mainly sold directly between the slag producer and the converter of pentoxide to ferrovanadium. Slag prices are set on the basis of the vanadium and impurity content of the slag, and the quoted producer price of V_2O_5 (see below) using a pricing formula. However, the actual figures in the pricing formula are unknown to most actors on the market. According to one trader in the business, there is generally slag of this kind available at or just below slag price based on the pentoxide producer price.

For V_2O_5, two prices are generally quoted. The first price is quarterly producer price and the second is a free market price of V_2O_5 quoted as spot business contracts. The first is published by Highveld Steel & Vanadium, generally each quarter. The latter quotation (termed "other sources") always refers to a previous transaction. This means that the establishment of a price need not indicate that the commodity is available (or saleable) at the indicated price. During the major part of the 80's the Highveld producer price was kept unchanged for several quarters. Today, the price changes more often, although Highveld is as dominating in the market as before. However, as for slag, most V_2O_5 business is conducted between primary producers and ferroalloys producers and from the ferroalloy plant on to the steelworks. Only an estimated 15 per cent of the vanadium business goes through open trading. If this part of the business was to decline further, it is likely that the open market prices will loose their significance.

The price of Highveld material is generally formed as a result of several factors. Among these, the supplied and purchased volumes, the rate of which the volumes are accepted on the market at

Figure 3. Vanadium pentoxide prices from 1950 to 1990, current and in 1990 USD



Note: (1950 - 1980) U.S. producer prices, (1980 - 1990) Spot market quotations in yearly averages. Fixt 1990 U.S. dollar prices were calulated using an international producer price index (metals) from the Swedish Riksbank.
Source: (1950 - 1980) Vincent [op. cit.], (1980 - 1990) Metal Bulletin [1980 et. seq.]

Table 8. Vanadium trade between different geographical regions (selected countries), in tonnes V

Country	Exports			Imports		
	1985	1987	1990	1985	1987	1990
Be/Ne/Lux						
Residues[1]	4 737	3 100	4 433	19 119	12 087	–
Pentoxide	451	3 095	66	4 205	4 205	5 657
Metal	337	291	–	350	–	–
France						
Pentoxide	–	–	–	2 218	127	282
Metal	–	–	–	141	111	85
Germany[2]						
Residues	4 296	3 742	171	31 635	32 439	25 923
Pentoxide		504	220	1 870	155	597
Metal	377	312	410	267	40	19
Italy						
Residues	1 901	1 901	–	2 508	1 538	184
Pentoxide	–	–	–	69	95	401
Metal	–	–	–	35	22	–
Spain						
Pentoxide	–	–	–	145	216	2
UK						
Pentoxide	80	18	–	260	255	226
Metal	12	142	22	129	238	257
South Africa						
Pentoxide[3]	22 018	26 251	21 989	–	–	–
Canada						
Pentoxide	–	–		1 130	1 410	838
USA						
Residues	–	–		1 466	22 251	50 464
Pentoxide	1 385	1 369	2 570	111	463	1 004
Metal	–	–	–	–	–	115
Japan						
Pentoxide	–	–	–	3 786	2 763	4 796
Metal	–	–	–	–	–	104
Finland						
Pentoxide[4]	2 600	1 500	–	–	–	–
Brazil						
Pentoxide	–	–	–	1 210	998	481
USSR						
Residues[4]	12 000	10 000	6 600	–	–	–
China						
Pentoxide[4]	3 100	4 200	3 400	–	–	–

1. Including slags; 2. Only former FR. Germany; 3. Including V_2O_5 in slags; 4. Estimated.
Source: World Mineral Statistics (British Geological Survey).

the time of the sales, and the development on the user market (the steel market) is the most important. Highveld first published its list price in 1970 and has since acted as a guide to the market and a restrain against excessive fluctuations. However, in periods of unusually high or low demand this price has been ignored. During boom situations, like the one in 1988/89, control of the price levels was completely lost. Today the Highveld list price is more or less unworkable for many convertors of V_2O_5 and does not reflect the market price. The list price is only applicable to a relatively small volume of world consumption and attempts to increase this volume would (at least in the short term) most probably only be successsful at the expense of lower and more unstable prices.

Free market producers will price their material in relationship to the Highveld quarterly price but the material is often put on the market at prices way above the producer price. If no quantities are sold at this price level, the price is lowered and the producers will try to maximize cash flow. Production capacity will be mothballed to keep prices at a reasonable level. However, there is often up to as much as a six-month delay between a slowdown in demand and the setting of the price in the V_2O_5 producing end.

Vanadium pentoxide is the most common commodity in vanadium trade and the different prices in the up and downstream vanadium markets (slag, ferrovanadium) are based on the pentoxide price. The transactions of the market are generally carried out through a trader and/or a trader/agent. There are a few independent traders taking positions of their own in the market.

To the steelworks, ferrovanadium is generally sold in lots of 20 - 40 t. For the metal, a price range is published in which the prices dealt during the time quoted are being presented. Ferrovanadium prices are theoretically set based on the V_2O_5-list prices plus a conversion cost of 3 – 4 USD per vanadium unit contained in V_2O_5, and roughly 3 per cent conversion loss. The conversion cost is dependant on the aluminium price since a lot of aluminium is used in the metallothermic conversion of V_2O_5 to ferrovanadium. However, there may be a premium or a backwardation of these prices. Actually, the V_2O_5 and the ferrovanadium markets may act somewhat independently.

Trade and price development

The international trade with vanadium commodities has shifted with the depletion of different sources of vanadium. In the 1950s phosphate rock and uranium ore mostly found in the USA were the most prominent sources of vanadium. Since the US was also the major consumer, there was little need for world trade. From the early 1960s, titanomagnetites were more and more taking over as the main source of vanadium. This has lead to a more diversified trade, from the beginning mainly from South Africa and Scandinavia (Finland and Norway). Today the main slag and pentoxide exporters are South Africa and formerly centrally planned economies as China and the USSR. A third shift in international trade might take place as other raw material such as vanadium containing sands in New Zealand and Australia and oil ashes become more important. Trade with high grade ferrovanadium has co-developed with the vanadium commodity trade. Imports and exports of vanadium during the last years are shown in table 8.

A large exporter of high-grade ferrovanadium (although not noted in the table due to proprietary statistics) is Austria (through Treibacher Chemishe Werke). It is also noteworthy that Germany is a large importer as well as exporter. Other large importers are France and Sweden (not specified in the table for above mentioned reasons). Another clearly identifiable feature is the closure of US mining capacity. Few figures regarding the trade within or into the formerly centrally planned economies are public but there are indications that barter trade occurs with neighbouring countries, mainly Germany.

Vanadium prices were rather stable from the beginning of vanadium trading until approximately 1967, when the HSLA steel began to be develop. Prices then rose until 1980 when the general downturn in steel hit the market. However, the prices recovered during the 1980's and ended in a price rally 1987 to 1989[21], but subsequently prices have turned down again. The price development of vanadium, as contained in V_2O_5, from 1950 to 1990 is shown in figure 3. On a real term basis (constant 1990 prices) the prices have tended to fall although no direct pattern can be spotted. However, from 1980 the constant prices have had a declining feature disregarding the price rally 1987 – 1989.

Vanadium as a strategic metal

Vanadium is sometimes regarded as a strategic metal although it is quite common in the crust of the earth. However, what is strategic or not is an ambiguous concept.[22] For a metal, it must be difficult to substitute (in a certain, short- time horizon) and its availability must constitute a critical precondition for the maintenance of important segments of industrial activity. Moreover, it has to be scarce in those countries where the major parts of the applications are at hand. Besides vanadium, these prerequisites also apply to other metals where the main applications are as steel-alloying metals. This group consists of chromium, manganese, niobium, molybdenum and tungsten.

In the case of vanadium, developed countries had 24 per cent total world reserves in 1990 and the centrally planned economies had 76 per cent (figures from developing countries were not available). In primary production, developed countries contributed with 55 per cent and the centrally planned with 45 per cent[23]. From an OECD perspective (mainly Western Europe), the degree of self sufficiency is low. If the time horizon is chosen rather short, say one year, the output of vanadium could be regarded as sensitive macroeconomic disturbances, i.e. a breakdown in trade between the OECD-countries and the, at the time, formerly centrally planned economies.

The major part of the raw material resources is concentrated to three countries: the former USSR, China and the South African Republic. Accordingly, the development in these countries or rather geographical areas, must be studied in more detail. Earlier, the centrally planned economies were one of the geographical areas upon which the western world could have been dependant. Due to the development in USSR, it is not fruitful to discuss possible long run strategies at present.

It is also clear that the Russian Ministry of Metallurgy, which was the operating organization within the USSR, is very reluctant to reveal anything regarding its production capacity and sales. In the short run, it is rather likely that sales from Russia (and its allies in the C.I.S.) will continue without any major disturbances to finance the rebuilding of its economy.

For China, the picture is somewhat different. It is well known that China has abundant resources of vanadium. The first works in China for extraction of vanadium by hydrometallurgy was built as early as 1942[24]. Today, the general ferroalloy industry in China is separated into two categories, the key enterprises that belong to the Ministry of Metallurgical Industry and the local mini ferroalloy plants. The key enterprises produced roughly 1 Mt ferroalloys in 1988. This was considered to be around 70 per cent of the total output. The local mini ferroalloy plants, numbering 57 in 1988, had a total production capacity of 250 kt ferroalloys. Of the key enterprises, totally 15, only two of them, Nanjing and Erme, produces vanadium pentoxide and ferrovanadium. Both main ferroalloy plants produce low value ferroalloys such as ferrovanadium with 40 or 50 per cent vanadium apart from some 80 per cent ferrovanadium.

A second economical/geographical area of importance in vanadium trade is South Africa. If the shares of (primary) production, exports and reserves reflect the importance of a country's minerals it is undisputable that the western world's dependence on South African material has grown from the 1970s.[25] However, the dependence can be disputed. Bolton[26] points to three factors. First, the reserves and production capacity (and hence possible exports) are in the hands of privately – and sometimes transnational companies. These are not directly controlled by the government and it is in their interest that trade continues or they would quickly perish. Secondly, if the official South African figures were recalculated, compensating for material from different other sources (which are perennial) the dependence of South African material is less obvious. Thirdly, in the case of a withdrawal of South African material from the market the uneconomic sources of today would easily be economic and put into production in a matter of a few months. Such behaviour was seen during the price rally of the late 1980s. A withdrawal of South African material could also lead to a larger output from the formally centrally planned economies or China. For them, this would be an easy way of obtaining hard currency.

Finally, in the light of the recent development in South Africa, there is – presently – no incentive for South African officials to use the strategic mineral "weapon" on the western world as the earlier sanctions have been completely withdrawn. Accordingly, apart from China, the development path of vanadium seems to be one moving away from the strategic group into a more ordinary competitive setting.

A changing face?

The vanadium market has been changing slightly during the last decade. On the one hand, the number of producers of the end-product in the production chain, ferrovanadium, has declined, so have prices of both metal and semi-finished products. Furthermore, as a conclusion from the latest paragraph, vanadium may be losing its place among the strategic minerals, if it actually ever had one. On the other hand, the main actors on the market have been active for some time and the applications of vanadium in steel are more then twenty years old. So, if there actually have been changes in the vanadium industry, these are most likely to be found in the market arrangements. Such changes may well have several reasons, inter alia changes in the contract structure on the market or changes in the homogeneity of the product. Contract changes in a commodity market will influence the price formation. Inertia in the price formation, i.e. contracts over longer periods of time, will lead to an adjustment in quantity instead of price. Changes from long term contracts to shorter contracts and more spot deals may, in the long run, lead to a more efficient, anonymous market in the final stages as well in primary production (ore and slag). There seems to be an unspoken policy to move the producer prices of V_2O_5 more closely in line with the free market price.[27] In case of an increased and diversified slag output (due to new low cost ventures in primary production) it is likely that there will be changes in also the slag pricing system.

Changes in the contract structure also cause a greater difficulty to foresee macroeconomic effects. The contract structure is not invariant of exogenous economic change such as inflation rate, price variability and economic policy. This means that the uncertainty of the market may increase. Under such circumstances the amount of vertical integration tends to increase and there will be a tendency to product standardization. Clearly the vanadium market is moving in that direction, since, presently, 80 per cent FeV is almost exclusively used as a steel additive. This has also called for a greater demand of product quality, i.e., well-defined product specifications. Ferrovanadium added to steel has got more narrow ranges for impurities such as phosphorus, sulphur and oxygen than before. This means that earlier – more impurity rich – masteralloys of vanadium have been abolished from the product program and that the list of possible producers has been cut shorter. In practice, only local technological choices from high quality ore are possible.

Technical progress continuously reduces the cost of exploitation of poorer resources that are used to compensate for the richer, depleted ones. Due to recirculation, the relative price difference between mined and recycled material will also be a major determining factor on the price necessary to attract new ventures. Such a price must cover the full cost of a new venture and the full cost must, in turn, be able to compete with the operating cost of existing operations. To estimate the existing operating cost (of vanadium production) is notoriously difficult. This is mainly due to the beneficiation of vanadium as a by- or co-product. However, market prices around 11 USD/kg for vanadium in ferrovanadium or 2.20 USD/lb for V_2O_5 are clearly inadequate. At these price levels practically no production units will operate profitably on a long term basis. It is reasonable to believe that prices above 3 USD/lb V_2O_5 would attract new investment.[28]

Finally, let me venture onto the thin ice of forecasting. It is reasonable to believe that a development in the vanadium business will be dependent on infrastructural development (housing etc.) or development on the material side (new steel grades). Alas, my professional competence is in neither of these specialties – on the contrary it lies mainly on the production side. Accordingly, a look into my crystal ball will mainly show possible vanadium output development. Given a slightly increasing investment behaviour, the market for vanadium could be brighter in the 1990s than it has been during the 1980s. Darkening clouds may be the several ventures of vanadium commodity production that have been discussed although a large overcapacity exists at the moment. If these projects are put on stream, it could mean a continuance of excess supply. In such a case, the price forecast for vanadium would still be a bit gloomy into the forthcoming new millennium.

Notes

1. The following alloys are usually termed "noble alloys" (see, e.g., *Metal Bulletin*): Ferromolybdenum, Ferrotitanium, Ferrotungsten and Ferrovanadium.

2. Originally published in *Jerncontoirets Annaler*, p.254 - 261, 1831: "Om Vanadium, en ny metall, funnen uti stångjern, som är tillverkadt af malm ifrån Taberget i Småland/On Vanadium, a new metal, found in iron from ore mined at Taberget in Småland".

3. see von Seth R.: "Om vanadinens förekomst i järnmalmer, dess förehållande vid de järnmetallurgiska proceserna samt möjligheter till dess tillgodogörande/On the occurrence of vanadium in iron ore, its distribution during iron metallurgical processes and possibilities to beneficiate it", *Jernkontorets Annaler*, häfte 11.

4. see U.S. Bureau of Mines: Mineral Facts and Problems, *Bureau of Mines Bulletin* 675, United States Department of the Interior, Publications Distribution in Pittsburgh, 1985. For further statistics from USBM see: Mineral Commodity Profiles, Vanadium, 1983, et seq., *Minerals Yearbook*, Vanadium, 1987 et seq. and *Mineral Commodity Summaries*, 1990 et seq.

5. *Minerals Handbook 1992 – 93*, ed. P. Crowson; Stockton press 1993. All Minerals Handbook figures refers to 1991 average prices and 1990 production levels.

6. An extensive overview of different vanadium producing technologies is given by Gupta, *Extractive metallurgy of niobium, tantalum and vanadium*, International Metals Reviews, The Metals Society, London, 1984 and Gupta & Krishnamurthy, *Extractive Metallurgy of Vanadium*, Elsevier Science Publishers, Elsevier Press, Amsterdam, 1992.

7. Value of contained metal in annual production was estimated to MUSD 400 in *Minerals Handbook*, 1993, p XV.

8. Due to a special Swedish interest in vanadium production, a discussion of this is carried out in SOU 1989:93, *Prospekteringspolitik – Betänkande av mineralråvarukommittén*, Rapportdel, Bilaga 11 Vanadin, Allmänna Förlaget, Stockholm, p 380. The discussion is based on unpublished figures originating from Highveld Steel & Vanadium. To my knowledge, the only project actually carried out was the New Zealand Steel venture.

9. This assessment was offered to me by traders in the business (see below) and confirmed by my own contacts with various sources.

10. A further discussion of the development in the former eastern countries may be found in Tilton (ed.), *World Metal Demand: Trends and Prospects*, Resources for the Future, Washington D.C., USA, 1990.

11. Unless otherwise stated, statistical figures regarding steel may be found in the *Steel Statistical Yearbook* from the International Iron and Steel Institute in Bruxelles, Belgium.

12. According to unpublished material from the large vanadium producer GfE (Gesellshaft für Electrometallurgie) in Nürnberg.

13. The development of vanadium applications is treated in Sage, *Vanadium*, Proc. Int'l Conf. "Future Metals Strategy", TMS, London, England, 1979, p 86. The current applications are found in Bohunovsky: *Trends in the vanadium market*, Pre-print, Fifth Ferro Alloys Conf. Monte Carlo, November 1985 and in Hess and Sattelberger, *Vanadium, production and application*, Proc. Seventh Int. Ferro-alloys Conf., Monte Carlo, November 1989, p 45.

14. A more thorough discussion on the uses of vanadium, and the bases for the discussion above, is found in Paton R. and Luyckx S, A Literature review of the Properties and Uses of vanadium, in *Engineering Alloys and of Vanadium Carbide*, Report No. M270, Council for Mineral Technology, Randburg, South Africa, 1986, mainly p. 8, 18, 19 f.

15. According to an article in *Mining Engineering*, january 1991 p. 13, this was due to low uranium prices. Since a lot of the uranium production in other countries is subsidized by the governments, the cost-price relationship is disturbed and even though the U.S. mines are low cost producers they can not compete. This also implies that the uranium price will stay low for the foreseeable future, thus decreasing the vanadium output.

16. see Wang, *The Development of Vanadium Industry in China*, Proc. Fifth Int. Ferro-alloys Conf. Monte Carlo, November, 1989 and Kuang Di: *Developing Ferroalloys Industry in China*, Internal working paper, Department of Applied Process Metallurgy, KTH, 1989.

17. These figures are collected from several issues of *Metal Bulletin*. A compilation over several years was e.g. given on February 18, 1988 and February 14, 1991.

18. The former figure was derived from the *Ferro-alloy Directory*, Metal Bulletin Books Ltd, Surrey, U.K., First edition in 1984, p 310 ff. The second figure is an updated version based on the second edition, *Ferro-alloy Directory & Databook*, Metal Bulletin Books, 1988:113.

19. See e.g. *Metal Bulletin* Jan. 25, 1993, Dec. 17, 1992. After some time of low prices, Highveld Steel & Vanadium stopped publishing producer prices in *Metal Bulletin* from July 29 1993.

20. I am indebted to several actors and analysts in the vanadium industry for their kind help during various periods of drafting of this article (and previous work). The following passage is mainly based on interviews with the following people (in alphabetical order): E. Bengtsson, SSAB, Sweden; F. Brandeis, EC-Trading, Switzerland; J. Chigwidden, Highveld Steel & Vanadium Ltd, South African Republic; D. Hargrave, Brandeis Ltd, U.K.; H.E. Hillard, U.S. Bureau of Mines, USA; T. Kleist, Uddeholm AB, Sweden; A.M. Moreno, Metal Bulletin Ltd, U.K.; M. Storseth, Elkem PEA, Norway.

Written sources to the following paragraph are also Vincent, *The Vanadium Supply and*

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Demand Picture and Australia's Contribution, Proc. Third Int. Ferroalloys Conf. Athens, Greece, 1981; Hargrave, *The changing face of the vanadium market*, Pre.print, Eighth Int. Ferro-alloys Conf., Monte Carlo, November, 1991 and Bohunovsky (op. cit.). The development of vanadium trade is also discussed by Kraus: *Vanadium - Verbrauch und Verfugbarkeit*, Stahl u. Eisen 109 (1989) Nr. 11, pp 547 - 552.

21. According to Brandeis (see above) this was started by the failure to comply with orders by a japanese producer. This was confirmed by an article in *Metal Bulletin* June 6 1991, p7.

22. One of the original classifications of strategic metals was carried out by DeMille in *Strategic Minerals – A Summary of Uses, World Output, Stockpiles, Procurement*, McGraw-Hill, London and New York, 1947.

23. Developed countries are here defined as OECD plus South African Republic; the centrally planned countries were (at the time of the statistics): the former USSR, former Comecon including. East Germany, Peoples Republic of China, North Korea, North Vietnam, Albania, Mongolia, Cuba; developing countries are countries not included in the other two categories. Source of definition and figures: *Minerals Handbook* (op. cit.).

24. see Wang and Kuang Di (op. cit.).

25. see Ariovich: Strategic Importance of SA Minerals (South African) *Chamber of Mines Newsletter*, March 1984 and Owen: The Role of South Africa as a Supplier of Strategic Minerals, *Raw Materials Report*, Vol. 4, No 4 1986.

26. see Bolton: The Illusion of Dependence: South African minerals in the global economy, *Raw Materials Report*, Vol. 2, No. 3, 1983.

27. See e.g. *Metal Bulletin* Oct 10 1991, p11 and the Highveld withdrawal of price publishing in 1993.

28. See Hargrave (op. cit.) and *Metal Bulletin* Dec. 2 1991, p 13. ■

Western world vanadium industry: Ownership and control 1992

by Andreas Tegen

The table on the following page is an excerpt from Raw Materials Data, *the* database on ownership and production in the world's mineral industries. Raw Materials Data is compiled by the Raw Materials Group and is the only database of its kind covering more than 7 000 mining, refining and exploration companies active in more than 30 minerals. Readers of Raw Materials Report will regularly get exclusive excerpts from Raw Materials Data.

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The table on the following page shows the controlling companies in vanadium ranked by size of controlled production.

The controlling companies have the ability to act decisively on strategically important issues. Such issues include the broad policies of a company, decisions on large investments, buying or selling of subsidiaries and power to appoint or dismiss management. To be in control of a company does not necessarily include having a day-to-day influence over all its decisions. It is not always easy to define control exactly and it can also be a bit difficult to measure it accurately.

A company can be controlled through many means, of which ownership is the most common and important one. However, control can also be exercised through administrative and technical management, vertical integration, interlocking directorates, long term contracts, financing arrangements and proprietary technologies. In the table on this page, ownership and management are used when determining who is in control of a specific company.

The table does not include the state owned producers in the former USSR and China and it does not include vanadium produced from oils, spent catalysts etc.

Since no production statistics are released, all figures are estimates based on company statements on capacity changes etc in combination with national production figures.

Anglo American Corporation of South Africa (AAC), in turn controlled by the Oppenheimer family, is the undisputed leader of the league. AAC is one of the largest minerals companies in the world with a wide range of minerals and metals on its production list. AAC is active in all parts of the world, although its focus is still in South Africa. It is a leading controlling company in the production of gold, platinum group metals, diamonds,