

# VANADIUM

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In 2000, all U.S. vanadium production was from various industrial waste streams. Fewer than 10 firms, primarily in Arkansas, Louisiana, Texas, and Utah, processed materials such as vanadium-bearing iron slag, fly ash, petroleum residues, and spent catalysts to produce vanadium pentoxide, ferrovanadium, and vanadium metal. Recycling of vanadium was negligible; only small quantities of vanadium-based catalysts and vanadium-aluminum alloy were recycled.

Vanadium consumption in the United States decreased for the third consecutive year. Metallurgical applications in which vanadium was used as a minor alloying element with iron, steel, and titanium remained the dominant use and accounted for more than 90% of domestic consumption. The largest nonmetallurgical use for vanadium was in catalysts.

Six countries recovered vanadium from ores, concentrates, slag, or petroleum residues (table 7). China, Russia, and South Africa were the leading nations in vanadium production. In four of the five foreign countries, vanadium production was primarily a byproduct of iron mining and processing.

The U.S. Geological Survey (USGS) estimates that the vanadium reserve base is more than 27 million metric tons, a sufficiently large supply that by itself can satisfy the market for several hundred years at the present rate of consumption. Additionally, the expected increase recovery of vanadium from spent catalyst, fly ash, and petroleum residues will extend the viability of the reserve base significantly.

## Legislation and Government Programs

The U.S. Department of Commerce (DOC) conducted an expedited review of the antidumping duties on Russian ferrovanadium and nitrided vanadium. The DOC found that the

antidumping duties should be maintained. The duties ranged from 3.75% to 108%, depending on the producing company (Ryan's Notes, 2000a).

The U.S. International Trade Commission decided in September to conduct a full review of the antidumping duties on Russian ferrovanadium and nitrided vanadium (Ryan's Notes, 2000b). A ruling was expected in 2001.

## Production

Near midyear, CS Metals of Louisiana LLP commissioned a new plant in Convent, LA (Metals Week, 2000). The plant will process spent petroleum catalysts and at full capacity is expected to recover nearly 2,300 metric tons (t) per year of vanadium pentoxide, molybdenum oxide, and possibly some nickel.

## Consumption

In 2000, domestic vanadium consumption was 3,520 t. Although vanadium has many uses, metallurgical applications account for essentially all domestic consumption. Most vanadium is consumed in the form of ferrovanadium, which is used as a means of introducing vanadium into steels where it gives additional strength and toughness. Ferrovanadium is available as alloys containing 45% to 50% and 80% vanadium. The 45% to 50% grade is produced from slag and other vanadium-containing materials by the silicothermic reduction of vanadium pentoxide. Most of the 80% grade is produced by the aluminothermic reduction of vanadium pentoxide in the presence of steel scrap or by direct reduction in an electric arc furnace. Vanadium steels can be subdivided into microalloyed

## Vanadium in the 20th Century

Metallurgical research near the end of the 19th century had shown the benefits of adding vanadium to tool steels and machinery for added toughness and fatigue resistance. However, vanadium was not an important commercial metal in the early 20th century because it was relatively rare and therefore expensive as well as difficult to produce in a pure form. In 1901, the United States produced approximately 340 metric tons of ore containing uranium and vanadium primarily from mining operations in Colorado. The first commercial production of ferrovanadium occurred domestically in 1907.

The commercial importance of vanadium was established during the first third of the century. Discovery of high-grade deposits in Namibia, Peru, and Zambia, along with additional development of the deposits on the Colorado Plateau in the Western United States, did much to ensure a sufficient supply of vanadium. Metallurgical progress was also being made during this period in the production of ferrovanadium.

Simultaneously, commercial uses for vanadium-containing steels, such as in automobiles and armor plating, were being developed. Among the nonmetallurgical applications developed during this period was the use of vanadium pentoxide as a catalyst in the production of sulfuric acid. This type of catalyst was introduced into the United States in 1926 and gradually replaced platinum.

Vanadium uses changed little during the century. In 2000, metallurgical uses still dominated, accounting for more than 90% of domestic vanadium consumption. The source of vanadium supplies, however, changed significantly. Rather than recovering vanadium from ores as was done during the first half of the century, such materials as vanadium-bearing iron slag, fly ash, petroleum residues, and spent catalysts were processed to produce vanadium pentoxide, ferrovanadium, and vanadium metal.

or low-alloy steels, which generally contain less than 0.15% vanadium, and high-alloy steels, which contain as much as 5% vanadium. Nonmetallurgical applications include catalysts (which is the dominant use), ceramics, vanadium chemicals, and electronics.

The USGS derived vanadium consumption data from a voluntary survey of domestic consuming companies. For this survey, more than 80 vanadium companies were canvassed on a monthly or annual basis. Consumption data reported in tables 1 and 2 contain estimates for nonrespondents.

### Prices

In 2000, the domestic price for ferrovandium, as published in *Metal Bulletin*, ranged from \$3.85 to \$6.60 per pound, a wider range than the \$4.35 to \$6.25 range reported for 1999. The price reached its high in March and declined steadily throughout the remainder of the year. The lowest price was reported in December. The European ferrovandium price recorded its high for the year in March and its low in January. The European price ranged from \$7.45 to \$13.50 per kilogram compared with \$7.45 to \$13.70 in 1999.

*Metal Bulletin's* published price for domestic vanadium pentoxide ranged between \$1.25 and \$2.65 per pound in 2000. The price peaked in March and steadily declined throughout the year. In 1999, *Metal Bulletin's* vanadium pentoxide price ranged from \$1.25 to \$2.90 per pound.

### World Review

Nearly all the world's supply of vanadium is from primary sources. Six countries recovered vanadium from ores, concentrates, slag, or petroleum residues (table 7). The largest vanadium-producing nations remained China, Russia, and South Africa, with production primarily a byproduct of iron mining and processing. Japan and the United States were believed to be the only countries to recover significant quantities of vanadium from petroleum residues.

Recycling of vanadium was negligible. Its major use was as a minor element in iron, steel, and titanium-bearing alloys from which it is not extracted when those metals are recycled. Only small quantities of vanadium-based catalysts and vanadium-aluminum alloy were processed to recover vanadium.

In October, Precious Metal Australia Ltd. sold its 40%

interest in the Windimurram vanadium mine to its joint venture partner Xstrata AG (American Metal Market, 2000). Precious Metal Australia retained a 15% net profit interest in the mine.

### Outlook

In the near term, the major factor affecting the vanadium market will be the demand for steel. Longer term however, the consumption of vanadium will probably increase owing, in part, to the need for stronger and lighter steels and, in part, to the demand created by new applications, such as the vanadium battery. As in the United States, worldwide demand for vanadium is expected to be closely and directly related to the demand for steel.

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TABLE 1  
SALIENT VANADIUM STATISTICS 1/

(Metric tons of contained vanadium, unless otherwise specified)

	1996	1997	1998	1999	2000
United States:					
Production:					
Ore and concentrate:					
Recoverable vanadium 2/	W	W	W	W	W
Value thousand dollars	W	W	W	W	--
Vanadium oxide recovered from ore 3/	W	W	W	W	--
Vanadium recovered from petroleum residues 4/	3,730	NA	NA	NA	NA
Consumption	4,630	4,710	4,380	3,620 r/	3,520
Exports:					
Ferrovanadium	479	446	579	213	172
Vanadium pentoxide (anhydride)	241	614	681	747	653
Other oxides and hydroxides of vanadium	2,670	385	232	70	100
Imports for consumption:					
Ferrovanadium	1,880	1,840	1,620	1,930	2,510
Vanadium pentoxide (anhydride)	485	711	847	208	902
Other oxides and hydroxides of vanadium	11	126	33	--	14
Ore, slag, ash, residues	2,270	2,950	2,400	1,650	1,890
Stocks:					
Ferrovanadium	294	311	324	328 r/	257
Oxide	7	8	8	5 r/	5
Other 5/	4	4	4	15 r/	20
World, production from ore, concentrate, slag 6/	40,900	40,700	44,500	43,600 r/	43,000

r/ Revised. NA Not available. W Withheld to avoid disclosing company proprietary data. -- Zero.

1/ Data are rounded to no more than three significant digits.

2/ Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mill, plus vanadium recovered from ferrophosphorus slag derived from domestic phosphate rock.

3/ Produced directly from all domestic ores and ferrophosphorus slag; includes metavanadates.

4/ Includes vanadium recovered from fly ash, petroleum residues, and spent catalysts.

5/ Consists principally of vanadium-aluminum alloy, small quantities of other vanadium alloys, vanadium metal, and ammonium metavanadate.

6/ Excludes U.S. production.

TABLE 2  
U.S. CONSUMPTION OF VANADIUM, BY END USE AND FORM 1/

(Kilograms of contained vanadium)

	1999	2000
End use:		
Steel:		
Carbon	1,050,000 r/	1,190,000
Stainless and heat resisting	W	W
Full alloy	861,000 r/	685,000
High-strength low-alloy	865,000 r/	931,000
Tool	W	225,000
Total	2,770,000 r/	3,030,000
Cast irons	W	W
Superalloys	13,500	17,000
Alloys (excluding steels and superalloys):		
Welding and alloy hard-facing rods and materials	W	W
Other alloys 2/	402,000	392,000
Chemical and ceramic uses:		
Catalysts	W	W
Pigments	W	W
Miscellaneous and unspecified	433,000 r/	79,100
Total	3,620,000 r/	3,520,000
Form:		
Ferrovanadium	2,920,000 r/	2,920,000
Oxide	296,000 r/	189,000
Other 3/	409,000 r/	411,000
Total	3,620,000 r/	3,520,000

See footnotes at end of table.

TABLE 2--Continued  
U.S. CONSUMPTION OF VANADIUM, BY END USE AND FORM 1/

r/ Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

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

2/ Includes magnetic alloys.

3/ Consists principally of vanadium-aluminum alloy, small quantities of other vanadium alloys, vanadium metal, and ammonium metavanadate.

TABLE 3  
U.S. IMPORTS AND EXPORTS OF ALUMINUM-VANADIUM MASTER ALLOY  
AND VANADIUM METAL, INCLUDING WASTE AND SCRAP 1/

(Kilograms, gross weight)

	Aluminum-vanadium master alloy		Vanadium metal, including waste and scrap	
	Quantity	Value	Quantity	Value
<b>Imports for consumption:</b>				
1999	1,210,000	\$1,680,000	30,400	\$779,000
<b>2000:</b>				
Belgium	10,300	55,800	--	--
Germany	--	--	35,900	488,000
Netherlands	6,040	24,600	--	--
Russia	47	2,850	8830	438000
Taiwan	--	--	33	9,790
United Kingdom	--	--	1	2,940
Total	16,400	83,200	44,800	939,000
<b>Exports:</b>				
1999	514,000	6,440,000	177,000	3,200,000
<b>2000:</b>				
Australia	1010	13100	439	43,100
Belgium	--	--	464	10,500
Brazil	4250	125000	--	--
Canada	359,000	4,660,000	4,930	110,000
China	19,900	267,000	--	--
France	446	7600	9,840	109,000
Germany	--	--	33	28,700
Ireland	227	2,950	--	--
Israel	53,500	718,000	--	--
Italy	615	8,000	5	4990
Japan	43,200	670,000	1,110	25,000
Korea, Republic of	19,100	213,000	--	--
Malaysia	2,400	24,500	--	--
Mexico	166,000	2,250,000	--	--
El Salvador	424	12,500	--	--
South Africa	582	20,100	--	--
Spain	595	19,900	--	--
Switzerland	--	--	1	7,790
Taiwan	577	7500	--	--
United Kingdom	4910	94400	88400	1340000
Venezuela	--	--	59	4010
Total	677,000	9,120,000	105,000	1,680,000

-- Zero.

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

Source: U.S. Census Bureau.

TABLE 4  
U.S. IMPORTS AND EXPORTS OF FERROVANADIUM, VANADIUM PENTOXIDE (ANHYDRIDE), AND  
OTHER OXIDES AND HYDROXIDES OF VANADIUM 1/

(Kilograms, contained vanadium)

	Ferrovanadium		Vanadium pentoxide (anhydride) 2/		Other oxides and hydroxides of vanadium	
	Quantity	Value	Quantity	Value	Quantity	Value
<b>Imports for consumption:</b>						
1999	1,930,000	\$20,700,000	208,000	\$1,920,000	--	--
<b>2000:</b>						
Austria	289,000	3,000,000	--	--	--	--
Belgium	117,000	1,290,000	--	--	--	--
Canada	316,000	3,100,000	--	--	--	--
China	666,000	5,870,000	--	--	--	--
Czech Republic	537,000	5,480,000	--	--	--	--
Germany	4,020	35,100	2,350	29,400	--	--
Hong Kong	15,900	148,000	--	--	--	--
Japan	3,990	43,400	1,400	33,200	--	--
Luxembourg	--	--	--	--	50	\$3,000
Mexico	15,200	160,000	--	--	--	--
Netherlands	--	--	4,850	22,900	--	--
Niger	48,300	400,000	--	--	--	--
South Africa	480,000	5,230,000	894,000	6,170,000	--	--
Taiwan	12,600	136,000	--	--	--	--
United Kingdom	--	--	--	--	13,500	228,000
Total	2,510,000	24,900,000	902,000	6,260,000	13,500	231,000
<b>Exports:</b>						
1999	213,000	3,180,000	747,000	4,270,000	69,700	656,000
<b>2000:</b>						
Belgium	--	--	195,000	881,000	2,430	21,600
Brazil	--	--	800	6,600	6,210	32,500
Canada	133,000	1,760,000	--	--	22,700	248,000
Chile	--	--	274,000	1,280,000	--	--
France	--	--	181	3,980	--	--
Germany	--	--	18,100	93,200	16,600	145,000
Hong Kong	285	9,470	--	--	--	--
India	--	--	--	--	6,800	66,200
Italy	--	--	36,000	188,000	1,200	4,000
Japan	170	16,500	2,830	26,800	--	--
Korea, Republic of	--	--	49,400	469,000	--	--
Kuwait	--	--	--	--	430	3,820
Mexico	36,300	512,000	--	--	39,800	176,000
Panama	--	--	--	--	411	5,840
Peru	--	--	4,870	20,600	--	--
Russia	2,030	67,500	56,000	268,000	--	--
Saudi Arabia	--	--	4,560	45,600	--	--
Spain	--	--	9,000	49,000	--	--
Switzerland	--	--	18	3,010	--	--
Taiwan	--	--	--	--	532	4,730
Thailand	--	--	--	--	2,710	33,100
Venezuela	--	--	2,190	20,800	--	--
Total	172,000	2,360,000	653,000	3,360,000	99,800	741,000

-- Zero.

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

2/ May include catalysts containing vanadium pentoxide.

Source: U.S. Census Bureau.

TABLE 5  
U.S. IMPORTS FOR CONSUMPTION OF VANADIUM-BEARING ASH, RESIDUES, AND SLAG 1/

(Kilograms, vanadium pentoxide content)

Material and country	1999		2000	
	Quantity	Value	Quantity	Value
Ash and residues:				
Canada	146,000	\$101,000	91,600	\$80,500
Hungary	44,700	44,500	--	--
Italy	519,000	319,000	807,000	584,000
Mexico	856,000	5,740,000	1,100,000	869,000
Netherlands Antilles	13,200	9,890	--	--
United Kingdom	224,000	722,000	421,000	673,000
Total	1,800,000	6,940,000	2,420,000	2,210,000
Slag, from the manufacture of iron and steel, South Africa 2/	1,150,000	1,740,000	959,000	1,650,000

-- Zero.

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

2/ As adjusted by the U.S. Geological Survey.

Source: U.S. Census Bureau.

TABLE 6  
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS VANADIUM CHEMICALS 1/ 2/

(Kilograms, vanadium content)

Material and country	1999		2000	
	Quantity	Value	Quantity	Value
Sulfates:				
India	8	\$14,300	475	\$4,570
China	--	--	397	26,500
Total	8	14,300	872	31,000
Vanadates:				
Germany	77,700	724,000	47,600	328,000
Japan	24	79,500	78	165,000
South Africa	96,400	837,000	89,900	500,000
Switzerland	--	--	1	5,170
Taiwan	--	--	10,700	38,000
Total	174,000	1,640,000	148,000	1,040,000

-- Zero.

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

2/ Comprises vanadium ore and miscellaneous vanadium chemicals.

Source: U.S. Census Bureau.

TABLE 7  
VANADIUM: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons of contained vanadium)

Country	1996	1997	1998	1999	2000 e/
<b>Production from ores, concentrates, slag: 3/</b>					
China (in vanadiferous slag product) e/	14,000	15,000	15,500	16,000	16,000
Hungary e/	200	200	100	--	--
Kazakhstan e/	900	900	1,000	1,000	1,000
Russia e/	11,000	9,000	9,000	9,000	9,000
South Africa	14,770	15,590	18,868	17,612 r/	17,000
United States (recoverable vanadium)	W	W	W	W	--
<b>Total</b>	<b>40,900</b>	<b>40,700</b>	<b>44,500</b>	<b>43,600 r/</b>	<b>43,000</b>
<b>Production from petroleum residues, ash spent catalysts: 4/</b>					
Japan e/	245	245	245	245	245
United States	3,730	NA	NA	NA	NA
<b>Total</b>	<b>3,980</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>
<b>Grand total</b>	<b>44,800</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>

e/ Estimated. r/ Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

1/ World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

2/ In addition to the countries listed, vanadium is also recovered from petroleum residues in Germany and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through June 7, 2001.

3/ Production in this section is credited to the country that was the origin of the vanadiferous raw material.

4/ Production in this section is credited to the country where the vanadiferous product is extracted; available information is inadequate to permit crediting this output back to the country of origin of the vanadiferous raw material.