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Vanadium

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In 2018, the United States continued to be a major producer of vanadium products from secondary sources such as spent catalysts, ashes, and petroleum residues. The United States was 100% import reliant for vanadium, and total imports for consumption (measured in vanadium content) increased by 20% from those of 2017 (table 1). The United States imported 3,130 metric tons (t) of ferrovanadium (FeV), 4,600 t of vanadium pentoxide (V_2O_5), and 98 t of other oxides and hydroxides of vanadium (all measured in vanadium content), collectively valued at $407 million (table 3). The United States imported 281 t of aluminum-vanadium master alloys valued at $17.2 million and 28 t of vanadium metal valued at $2.2 million (table 4). Imports of ash and residues were 2,810 t (vanadium content) valued at $63.9 million (table 5). Imports of vanadium chemicals (sulfates and vanadates) were 398 t (vanadium content) valued at $17.6 million (table 6). The United States exported 575 t of FeV (vanadium content), 563 t of V_2O_5 (vanadium content), and 53 t (vanadium content) of other oxides and hydroxides of vanadium, collectively valued at $27.5 million (table 3). Exports of aluminum-vanadium master alloy were 161 t (gross weight) valued at $7.9 million, and exports of vanadium metal were 39 t (gross weight) valued at $2.6 million (table 4). Exports of ash and residues were 2,140 t (gross weight) valued at $1.6 million (table 5). Reported vanadium consumption in the United States was 5,660 t of contained vanadium, a 21% increase from reported consumption in 2017 (table 1). In 2018, estimated worldwide production of vanadium decreased by 7% to 71,200 t of contained vanadium, compared with the revised 76,600 t in 2017 (tables 1, 7).

Vanadium's primary use was as a hardening agent in steel, in which it is critical for imparting toughness and wear resistance. These properties are especially important in high-strength low-alloy (HSLA) steels. Vanadium-containing steels can be subdivided into microalloy or low-alloy steels that generally contain less than 0.15% vanadium and high-alloy steels that contain as much as 5% vanadium. Catalysts are the leading nonmetallurgical use for vanadium.

Legislation and Government Programs

In May 2018, the U.S. Department of the Interior, in coordination with other executive branch agencies, published a list of 35 critical minerals, including vanadium (U.S. Department of the Interior, Office of the Secretary, 2018). This list was developed to serve as an initial focus, pursuant to Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals" (Trump, 2017).

Production

Industry convention for describing the production of V_2O_5 usually applies the terms primary production, joint production, and secondary production according to the raw material source for production. Primary production occurs from mined ore as mineral concentrates derived from vanadiferous titanomagnetite (VTM). Joint production refers to vanadium slags that are produced during steelmaking. When a VTM iron ore is used to produce iron, vanadium is contained in the crude steel that must be extracted whether or not the finished steel will contain vanadium. Secondary vanadium production occurs from various industrial waste materials, such as vanadium-bearing fly ash, petroleum residues, and spent catalysts. Secondary vanadium production was the only source of U.S. vanadium production in 2018, taking place primarily in Arkansas, Ohio, Pennsylvania, and Texas, where processed waste materials were used to produce FeV, specialty alloys, vanadium chemicals, vanadium metal, and vanadium oxides.

The major vanadium commodities are aluminum-vanadium master alloys; FeV; vanadium-bearing ash, residues, and slag; vanadium chemicals; and V_2O_5 and other oxides and hydroxides of vanadium. Vanadium oxides are the most commonly produced vanadium compounds, although most V_2O_5 and trioxide are further processed into FeV. The most widely produced oxide is V_2O_5. In 2018, companies in the United States produced all these materials, except vanadiferous slag from the manufacture of iron and steel.

Energy Fuels Inc.'s (Toronto, Ontario, Canada) White Mesa Mill, near Blanding, UT, had the only vanadium coproduct recovery circuit in the United States. The mill had produced approximately 20,400 t of V_2O_5 (11,400 t of vanadium) during its 40-year operating history. In 2018, the company completed facility upgrades to the mill in order to begin vanadium recovery in January 2019. The company was expected to use new recovery techniques to recover vanadium from its existing tailings pond solutions. In early 2019, the mill produced the highest purity V_2O_5 in its history, averaging approximately 99.6% V_2O_5. The company expected to continue producing approximately 70 to 90 metric tons per month of V_2O_5 over a 16- to 20-month period. Production in 2019 was expected to be approximately 840 to 1,080 t of V_2O_5 (470 to 605 t of vanadium). Energy Fuels announced that production could be turned on and off at minimal cost in response to any vanadium market changes. The company expected to be able to recover approximately 1,800 t of V_2O_5 from the pond solutions, which resulted from past mineral processing operations. Energy Fuels had not produced vanadium since 2013 owing to low prices (Energy Fuels Inc., 2019, p. 1–2).

In October 2018, Energy Fuels began a 6-month test mining program at its La Sal Complex of uranium and vanadium mines in southeastern Utah. The company was testing new mining methods that selectively targeted areas of high-grade vanadium mineralization. After an initial 3-week testing period, the company reported that it had mined 420 t of material grading

1.67% V_2O_5. The company expected that the new mining methods would reduce costs and increase the value of the mined material as a result of a higher grade of ore being mined (Likata, 2018; Energy Fuels Inc., 2019, p. 1–2).

In May, Prophecy Development Corp. (Vancouver, British Columbia, Canada) submitted a plan of operation to the Bureau of Land Management for its Gibellini vanadium project in Eureka County, NV. Prophecy expected to update and complete a full feasibility study based on all previous work done (Prophecy Development Corp., 2019, p. 1). The previous feasibility study in 2011 projected mine production to average 5,170 metric tons per year (t/yr) of V_2O_5 (Prophecy Development Corp., 2017).

EVRAZ Stratcor, owned by EVRAZ plc (United Kingdom), operated a facility in Hot Springs, AR, where vanadium ash, residues, and other raw materials were converted into vanadium alloys and vanadium chemicals used by the chemical, steel, and titanium industries. Stratcor had the capacity to produce up to approximately 5,400 t/yr of vanadium oxide. Some of this oxide was then converted into a vanadium-aluminum alloy that met the requirements for titanium alloys used in jet aircraft and other aerospace applications. The Hot Springs facility also converted the vanadium oxide into many other specialty products used in the production of chemicals, gases, and storage batteries (EVRAZ plc, undated b). EVRAZ consisted of EVRAZ Nikom in Czechia, EVRAZ Stratcor in the United States, and EVRAZ Vanady Tula in Russia (EVRAZ plc, undated d).

AMG Vanadium LLC, a wholly owned subsidiary of AMG Advanced Metallurgical Group N.V. (Netherlands) in Cambridge, OH, was a major producer of FeV and other ferroalloys from spent oil refinery catalysts and powerplant residues (AMG Vanadium LLC, undated). In February, AMG Vanadium announced its plan to expand its current spent catalyst recycling operation after signing a new long-term multiyear agreement with an existing customer. The expansion was estimated to cost $35 million and involve the installation of a new flue gas desulfurization unit at the facility in Cambridge. The expansion was expected to be completed by the end of 2019 and would increase AMG Vanadium's recycling capacity by approximately 30% (Argus Metals International, 2019a).

Gladieux Metals Recycling LLC continued to recover vanadium from spent petroleum catalysts at its recycling plant in Freeport, TX (Gladieux Metals Recycling LLC, undated).

Consumption

The U.S. Geological Survey (USGS) derived vanadium consumption data from a voluntary survey of domestic consuming companies. For this survey, more than 50 companies were canvassed on a monthly or annual basis. Reported consumption and stocks data in tables 1 and 2 include estimates to account for nonrespondents.

Metallurgical applications continued to dominate U.S. vanadium use in 2018, accounting for 96% of reported consumption (table 2). Nonmetallurgical applications included batteries, catalysts, ceramics, electronics, and vanadium chemicals. The leading nonmetallurgical use was in catalysts. A number of vanadium chemicals were used in catalysts to manufacture a variety of industrial chemicals and to clean industrial process waste streams.

Most vanadium is consumed in the form of FeV, which is used to introduce vanadium into steel to provide additional strength and toughness. In 2018, 3,160 t of FeV was consumed representing 56% of the total amount of the reported vanadium consumed (table 2). Ferrovanadium is available as alloys containing either 45%-to-50% or 80% vanadium. The 45%-to-50%-grade FeV is produced by silicothermic reduction of V_2O_5 in slag or other vanadium-containing materials. Most of the 80%-grade FeV is produced by aluminothermic reduction of V_2O_5 in the presence of steel scrap or by direct reduction in an electric arc furnace.

Vanadium is becoming more widely used in green technology applications, especially in battery technology. Vanadium redox flow batteries (VRFBs), unlike conventional batteries, use a liquid vanadium electrolyte to store energy in separated storage tanks instead of in the power cell of the battery. The main advantages of the VRFB are that it can offer almost unlimited capacity simply by using sequentially larger storage tanks, can be left completely discharged for long periods of time with no ill effects, can be recharged by replacing the electrolyte if no power source is available to charge it, and suffers no permanent damage if the electrolytes are accidentally mixed (Johnstone, 2008). However, cost, equipment, and raw material availability continued to be barriers for entry into the battery market. Some of the U.S.-based manufacturers, all at different levels of establishing VRFB production lines, included Ashlawn Energy, LLC; Avalon Battery Corp.; Perennial Power Holdings, Inc.; StorEn Technologies Inc.; UniEnergy Technologies, LLC; Vionx Energy Corp.; and ViZn Energy Systems Inc.

Prices

In 2018, the U.S. average monthly price for domestic FeV (80% vanadium), as published by CRU Group, ranged from $24.489 to $55.856 per pound of contained vanadium, compared with $12.178 to $21.100 per pound reported in 2017. In 2018, the European average monthly price for FeV (80% vanadium) ranged from $53.111 to $121.889 per kilogram, compared with $24.681 to $45.059 per kilogram in 2017. The average monthly price for Chinese V_2O_5, published by CRU Group, ranged from $10.250 to $22.500 per pound from January through December 2018, compared with $7.063 to $11.875 per pound from July through December 2017. CRU Group discontinued publishing U.S. V_2O_5 prices as of August 1, 2017.

The 128% increase of the United States monthly average price of FeV from January to November, and the 120% increase of the Chinese monthly average price of V_2O_5 from January to October were mainly due to China's continued enforcement of environmental regulations, causing many vanadium producers to remain closed or operating at significantly lower levels, as well as China's ban on imports of vanadium slag feedstock. These factors, as well as the introduction of new high-strength rebar standards and the growing adoption of VRFBs, contributed to vanadium prices remaining at record-high levels.

World Review

Most of the world's supply of vanadium was derived from either primary or joint production. Production from these two sources is shown in table 7. The leading vanadium-producing nations remained China, Russia, and South Africa; these countries accounted for more than 92% of world production. Secondary production continued in Canada, Germany, Japan, and the United States, as well as several other European countries.

World vanadium reserves, estimated at more than 20 million metric tons (Mt), are likely sufficient to meet vanadium needs into the next century at the present rate of consumption. Increased recovery of vanadium from fly ash, petroleum residues, slag, and spent catalysts is not considered here and is expected to significantly extend the life of the reserves.

Australia.—In November, Neometals Ltd. announced that it would update the 2009 Definitive Feasibility Study (DFS) of the salt roast-leach operation at its Barrambie vanadium-titanium-magnetite project, approximately 80 kilometers (km) northwest of Sandstone in Western Australia. The company had a mining permit for Barrambie and owned 100% of the project through its subsidiary Australian Titanium Pty Ltd. The DFS was expected to be complete in the second quarter of 2019 (Neometals Ltd., 2018, p. 1–2).

Brazil.—Largo Resources Ltd.'s (Toronto, Ontario, Canada) Maracás Menchen Mine, located 813 km northeast of Brasilia, produced 9,830 t of V_2O_5 in 2018, a 6% increase compared with the 9,300 t of V_2O_5 produced in 2017. The company expected to produce between 10,000 and 11,000 t/yr of V_2O_5 in 2019. According to the company, the vanadium is contained within a massive titaniferous magnetite deposit that has much higher grades of V_2O_5 and iron than any other vanadium deposit in the world. The very low level of contaminants in the deposit, particularly silica, was expected to make the extraction and processing of vanadium much easier. This in turn was expected to lower operating costs and produce a superior high-purity concentrate (Largo Resources Ltd., 2019, undated).

Canada.—In February, VanadiumCorp Resource Inc. announced that it filed for an international patent application to secure rights for the new VanadiumCorp-Electrochem Processing Technology (VEPT). According to the companies, VEPT efficiently recovers vanadium compounds including vanadium pentoxide, vanadyl sulfate, as well as others from a variety of feedstocks containing vanadium (VanadiumCorp Resource Inc., 2018).

China.—Many vanadium producers in the Panzhihua Vanadium and Titanium High-Tech Industrial Development Zone continued to suspend or decrease vanadium production owing to local governments conducting environmental inspections following the discovery of polluted water in the Jinsha River in Panzhihua. Tighter environmental controls were also expected in other vanadium-producing regions. Pangang Group Vanadium Titanium & Resources Co., Ltd. continued to be the leading Chinese vanadium producer, with operations located in Panzhihua. The company had the capacity to produce approximately 24,000 t/yr of vanadium (SP Angel Corporate Finance LLP, 2018, p. 20).

In February 2018, the Standardization Administration of China (SAC) released a new standard for high-strength rebar that would decrease the use of substandard steels in construction to make buildings in China more earthquake resistant. The implementation date for the new standard was November 1, 2018. The new rebar standard would eliminate the low-strength Grade 2 rebar, and the SAC authorized Grade 3, Grade 4, and Grade 5 high-strength standards. The newly authorized standards would have 0.03% vanadium in Grade 3, 0.06% vanadium in Grade 4, and more than 0.1% vanadium in Grade 5 rebar. The increase of vanadium in rebar was expected to increase the overall consumption of vanadium in China by approximately 10,000 t/yr. However, this consumption increase estimate was expected to vary depending on the enforcement of these new rebar standards (Metal Bulletin, 2017; Li, 2018).

In January 2019, China's State Bureau of Quality and Technical Supervision conducted quality inspections of rebar producers in small steel mills to ensure that they had adopted the new rebar standards. It was reported that approximately 30% to 40% of mills had not fully switched to the new standards. Many of the small mills could not afford to implement the technology needed to produce the upgraded rebar (Argus Metals International, 2019b).

At yearend 2017, five Government agencies, including the Ministry of Environmental Protection and the Ministry of Commerce, jointly issued an import ban on 24 types of solid waste, including vanadium slag. The ban on four types of vanadium slag imports was expected to reduce the amount of raw material available for V_2O_5 production in China. In April 2018, authorities issued an additional import ban on vanadium waste and scrap that would go into effect at yearend 2019. Additional measures to further restrict the import of solid waste were expected to be announced (Metal Bulletin, 2018; Zhu, 2018).

Some of the China-based VRFB companies included Dalian Rongke Power Co. Ltd., Golden Energy Century Ltd., Golden Energy Fuel Cell Co. Ltd., Shanghai Shenli Technology Co., Ltd., and VRB Energy. According to the company, Shanghai Shenli Technology was funded by the Ministry of Science and Technology of China and was financially supported by the Shanghai municipal government (Shanghai Shenli Technology Co., Ltd., undated).

In 2017, the China National Development and Reform Commission called for more investment in energy storage, specifically flow batteries. One such project underway was the 800-megawatthour vanadium energy storage project in Dalian in northern China. The project, built by UniEnergy Technologies LLC (Seattle, WA) and Rongke Power, was expected to come online in 2020. VRB Energy commissioned a 12-megawatthour energy storage project in Hubei Province. This demonstration project was expected to serve as an example for larger future projects (Colthorpe, 2018).

Czechia.—EVRAZ Nikom had one processing facility, which was used to process V_2O_5 from Russia and China and also vanadium trioxide from Bushveld Minerals Ltd.'s Vametco Mine into FeV. Nikom's FeV production capacity was 4,600 t/yr (EVRAZ plc, undated a).

Kazakhstan.—Ferro-Alloy Resources Ltd. (FAR) (United Kingdom) announced that it had completed a feasibility study to develop its Balasausqandiq vanadium project in

Kyzylordinskaya Oblast, in the south of Kazakhstan, and was expected to build a new processing facility in two phases. Phase 1 was expected to treat 1 million metric tons per year (Mt/yr) of ore to produce 5,600 t/yr of V_2O_5. Phase 2 was expected to increase the ore treated to 4 Mt/yr, producing 22,400 t/yr of V_2O_5 (Ferro-Alloy Resources Ltd., 2019, p. 1–3.

In addition to developing the Balasausqandiq vanadium project, FAR continued to produce approximately 125 t/yr of V_2O_5 equivalent in the form of ammonium metavanadate (AMV) at its existing processing facility from purchased concentrates and other vanadium-containing materials. The company was expected to install equipment to convert AMV to V_2O_5 and increase capacity to up to 1,500 t/yr of V_2O_5 (Ferro-Alloy Resources Ltd., 2019, p. 1–2).

Russia.—EVRAZ Nizhny Tagil Metallurgical plant (NTMK), an integrated metallurgical complex located in Nizhny Tagil in the Sverdlovsk region, continued to be one of the world's leading processors of VTM. The Vanady Tula facility, located 200 km south of Moscow, used low-cost, highly efficient technology to process the vanadium slag produced by NTMK (EVRAZ plc, undated c). Vanady Tula had a capacity of 5,000 t/yr of FeV and 7,500 t/yr of V_2O_5 in its electrometallurgical and hydrometallurgical plants (EVRAZ plc, 2016, p. 62).

South Africa.—With the closure of EVRAZ Highveld Steel and Vanadium Ltd.'s operations during 2016, Bushveld Minerals Ltd.'s Vametco vanadium mine and Glencore plc's Rhovan facility were South Africa's only active primary vanadium producers in 2018. Bushveld announced that its Vametco vanadium mine and plant in Brits, North West Province, produced 2,560 t of contained vanadium in the form of vanadium nitride and vanadium oxide in 2018 compared with 2,650 t of contained vanadium in 2017 (Bushveld Minerals Ltd., 2019, p. 7). The company attributed the slight decrease to the 37.5 days of stoppages at its plant. Labor grievances accounted for 22.5 days of the stoppages. Bushveld announced that it would produce more vanadium at Vametco in 2019 because it was not anticipating any more plant stoppages. The company had commenced a multiphased expansion project to increase annual production at Vametco. Phase II of the expansion project was completed in June, increasing capacity to 3,750 t/yr of vanadium. Vametco used the standard salt roast and leach process to produce a trademark vanadium carbon nitride product called Nitrovan (SP Angel Corporate Finance LLP, 2019, p. 1–3).

Glencore plc (Switzerland) announced that its Rhovan vanadium facility, 30 km northwest of Brits, produced 9,160 t of V_2O_5 in 2018, a 3% decrease compared with 9,480 t of V_2O_5 produced in 2017 (Glencore plc, 2019, p. 77).

Outlook

China's continued commitment to reduce environmental pollution resulted in a reduction of local vanadium production and lower vanadium exports from China. At the same time, vanadium demand in China is expected to continue to increase following the revision to its standards of rebar products. The new standards increased the vanadium content in rebar products, which in turn increased vanadium consumption in China. Many vanadium producers in China have been forced to direct most of their production back into the Chinese market (Argus Metals International, 2019c).

The World Steel Association forecast global steel consumption to increase by 1.3% in 2019, followed by growth of 1.0% in 2019 (World Steel Association, 2019). Because almost all vanadium is consumed in the production of steel, consumption trends are greatly influenced by trends in steel production; however, the use of vanadium in a wider range of steels has continued to increase. The outlook for consumption in nonferrous alloys is largely dependent on trends in consumption for titanium alloys in business, commercial, and military aircraft.

In addition to growth from the steel sector, one area of continued growth was in the energy storage market, specifically with VRFBs. China, India, and the United States are expected to account for two-thirds of the global renewable energy expansion to 2022. All European Union countries have adopted national renewable energy action plans showing what actions they intend to take to meet their renewable energy targets (European Commission, undated). Many countries are seeking to meet renewable energy targets by 2022 or earlier, and VRFB storage is proving to be a potential solution, with many countries having numerous implementations already underway. According to the U.S. Department of Energy's global energy storage database, 70 VRFB storage projects in 20 countries began construction or were in operation as of July 2019 (U.S. Department of Energy, undated).

Some disadvantages of VRFBs include the high cost of the vanadium electrolyte used in the battery as well as the system complexity of the batteries. These factors make it difficult for VRFBs to compete with lithium ion batteries. The market leader in flow battery chemistry was vanadium, but researchers continued to work on other chemistries that could potentially be less expensive (Maloney, 2017). Companies are expected to continue to improve VRFB batteries to make them more competitive in the battery market.

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TABLE 1
SALIENT VANADIUM STATISTICS[1]

(Metric tons of contained vanadium, unless otherwise specified)

	2014	2015	2016	2017	2018
United States:					
Production, ore and concentrate, recoverable vanadium	--	--	--	--	--
Consumption, reported	4,860 r	4,720 r	4,620 r	4,680 r	5,660
Imports for consumption:					
Vanadium ores and concentrates	--	72	18	1	330
Ferrovanadium	3,230	1,980	1,590	2,810	3,130
Vanadium pentoxide (anhydride)	3,410	2,870	2,460	3,400	4,600
Oxides and hydroxides, other	104	94	660	148	98
Aluminum-vanadium master alloy	320	143	157	288	281
Ash and residues[2]	3,450	4,600	2,820	2,540	2,810
Hydrides and nitrides, of vanadium	86	106	82	173	72
Sulfates	19	13	12	4	9
Vanadates	197	173	313	349	389
Vanadium metal	117	135	33	54	28
Total imports	10,900 r	10,200 r	8,150 r	9,770 r	11,700
Exports:					
Ferrovanadium	253	122	400	229	575
Vanadium pentoxide (anhydride)	201	356	5	126 r	563
Oxides and hydroxides, other	350	100	81	148	53
Aluminum-vanadium master alloy[3]	443	229	95	236	161
Ash and residues[2, 3]	2,300	385 r	1,100	2,870	2,140
Vanadium metal[3]	32	5	19	59	39
Stocks, yearend:					
Ferrovanadium	100	96	98	87	147
Other[4]	40 r	40 r	40 r	38 r	38
World, production from ore, concentrate, slag	91,800 r	88,100 r	74,500 r	76,600 r	71,200

[r]Revised. -- Zero.

[1]Table includes data available through November 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Not from the manufacture of iron and steel.

[3]Gross weight.

[4]Includes vanadium-aluminum alloy, other vanadium alloys, vanadium metal, vanadium pentoxide, vanadates, chlorides, and other specialty chemicals.

TABLE 2
U.S. REPORTED CONSUMPTION OF VANADIUM, BY END USE AND FORM[1, 2]

(Kilograms of contained vanadium)

	2017	2018
End use:		
Steel:		
Carbon	755,000	798,000
Full alloy	1,260,000 r	1,270,000
High-strength low-alloy	W	W
Stainless and heat resisting	62,400	62,700
Tool	W	W
Total	2,080,000 r	2,130,000
Cast irons	W	W
Alloys (including steels and superalloys)	1,560,000	2,440,000
Chemical and ceramic:		
Catalysts	W	W
Pigments	W	W
Miscellaneous and unspecified[3]	1,040,000 r	1,090,000
Grand total	4,680,000 r	5,660,000
Form:		
Ferrovanadium	3,060,000 r	3,160,000
Other[4]	1,620,000 r	2,500,000
Total	4,680,000 r	5,660,000

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

[1]Table includes data available through November 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes U.S. Geological Survey estimates.

[3]Includes electrical steel and unspecified steel.

[4]Includes vanadium-aluminum alloy, other vanadium alloys, vanadium metal, vanadium pentoxide, vanadates, chlorides, and other specialty chemicals.

TABLE 3
U.S. IMPORTS AND EXPORTS OF FERROVANADIUM, VANADIUM PENTOXIDE (ANHYDRIDE), AND OTHER OXIDES AND HYDROXIDES OF VANADIUM[1]

(Kilograms unless otherwise specified)

	Ferrovanadium[2]			Vanadium pentoxide (anhydride)[3]			Other oxides and hydroxides of vanadium[4]		
Country or locality	Gross weight	Contained weight	Value	Gross weight	Contained weight	Value	Gross weight	Contained weight	Value
Imports for consumption:									
2017	3,880,000	2,810,000	$92,800,000	4,020,000	3,400,000	$60,300,000	224,000	148,000	$3,680,000
2018:									
Austria	2,210,000	1,690,000	119,000,000	--	--	--	9,000	6,230	441,000
Brazil	--	--	--	2,280,000	2,270,000	86,900,000	--	--	--
Canada	1,070,000	837,000	41,500,000	--	--	--	--	--	--
China	--	--	--	646,000	591,000	23,600,000	--	--	--
Czechia	(5)	(5)	32,300,000	--	--	--	--	--	--
Germany	499	404	31,300	110,000	90,000	4,030,000	36	23	8,870
India	108,000	84,400	5,100,000	--	--	--	150	97	11,400
Japan	222,000	122,000	7,260,000	--	--	--	--	--	--
Korea, Republic of	11,000	8,800	629,000	100,000	98,100	3,890,000	--	--	--
Latvia	244,000	129,000	6,510,000	--	--	--	--	--	--
Russia	258,000	207,000	14,100,000	--	--	--	--	--	--
South Africa	3,900	3,120	313,000	1,470,000	1,460,000	49,600,000	140,000	91,300	4,990,000
Switzerland	--	--	--	13,800	13,300	502,000	--	--	--
Taiwan	--	--	--	83,200	80,500	2,280,000	--	--	--
Ukraine	83,300	43,400	3,880,000	--	--	--	--	--	--
Total	4,210,000	3,130,000	231,000,000	4,700,000	4,600,000	171,000,000	149,000	97,600	5,450,000
Exports:									
2017	300,000	229,000	6,000,000	XX	127,000	1,570,000	XX	148,000	1,690,000
2018:									
Argentina	--	--	--	NA	14,700	140,000	--	--	--
Australia	--	--	--	NA	305	2,900	--	--	--
Brazil	125	94	8,490	--	--	--	--	--	--
Canada	197,000	148,000	5,120,000	--	--	--	NA	7,260	68,900
Chile	5,890	4,420	147,000	--	--	--	--	--	--
China	--	--	--	--	--	--	NA	1,630	7,670
Colombia	1,170	880	36,100	--	--	--	--	--	--
Czechia	--	--	--	NA	39,700	1,620,000	--	--	--
Germany	--	--	--	--	--	--	NA	34,900	311,000
Guatemala	2,000	1,500	87,800	--	--	--	--	--	--
India	19,000	14,300	172,000	NA	476,000	3,960,000	--	--	--
Israel	928	696	6,610	--	--	--	--	--	--
Korea, Republic of	19,200	14,400	501,000	--	--	--	--	--	--
Mexico	560,000	382,000	14,400,000	NA	9,690	97,100	--	--	--
Nigeria	--	--	--	--	--	--	NA	741	6,590
Peru	14,900	9,280	391,000	--	--	--	--	--	--
Trinidad and Tobago	--	--	--	NA	22,700	245,000	NA	8,650	85,500
Total	820,000	575,000	20,900,000	XX	563,000	6,070,000	XX	53,200	480,000

NA Not available. XX Not applicable. -- Zero.

[1]Table includes data available through November 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes Harmonized Tariff Schedule code 7202.92.0000.

[3]May include catalysts that contain vanadium pentoxide. Includes Harmonized Tariff Schedule code 2825.30.0010.

[4]Includes Harmonized Tariff Schedule code 2825.30.0050.

[5]Data suppressed according to U.S. Census Bureau; not included in "Total."

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS AND EXPORTS OF ALUMINUM-VANADIUM MASTER ALLOYS
AND VANADIUM METAL, INCLUDING WASTE AND SCRAP[1]

(Kilograms unless otherwise specified)

	Aluminum-vanadium master alloy[2]			Vanadium metal, including waste and scrap[3]		
Country or locality	Gross weight	Contained weight	Value	Gross weight	Contained weight	Value
Imports for consumption:						
2017	443,000	288,000	$10,800,000	79,000	54,100	$2,600,000
2018:						
Austria	--	--	--	271	228	22,100
Belgium	1,000	650	71,200	--	--	--
Bulgaria	1	1	2,380	--	--	--
Canada	--	--	--	40	39	15,900
China	111,000	71,600	2,310,000	21,200	16,500	667,000
Czechia	16	16	20,000	--	--	--
Germany	21,900	17,500	460,000	12,600	8,630	809,000
Latvia	--	--	--	1,800	1,550	442,000
Japan	2,590	2,070	21,600	--	--	--
Russia	294,000	189,000	14,300,000	1,220	1,210	188,000
United Kingdom	805	802	11,400	244	244	61,000
Total	431,000	281,000	17,200,000	37,400	28,400	2,210,000
Exports:						
2017	236,000	XX	6,960,000	59,000	XX	1,540,000
2018:						
Australia	5,680	NA	642,000	8,000	NA	1,030,000
Austria	--	--	--	--	--	--
Belgium	--	--	--	5	NA	2,900
China	192	NA	7,400	--	--	--
Czechia	306	NA	11,800	--	--	--
Finland	--	--	--	5	NA	3,750
France	3,930	NA	155,000	--	--	--
Germany	3,040	NA	107,000	187	NA	7,230
Hungary	706	NA	10,000	--	--	--
Japan	7,480	NA	531,000	31,200	NA	1,560,000
Kazakhstan	126	NA	9,290	--	--	--
Korea, Republic of	18,500	NA	465,000	--	--	--
Russia	105,000	NA	5,330,000	--	--	--
Spain	2,790	NA	70,900	--	--	--
Switzerland	50	NA	2,830	--	--	--
United Kingdom	13,700	NA	563,000	--	--	--
Total	161,000	XX	7,910,000	39,400	XX	2,600,000

NA Not available. XX Not applicable. -- Zero.

[1]Table includes data available through November 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Aluminum-vanadium master alloy consisting of 35% aluminum and 64.5% vanadium. Includes Harmonized Tariff Schedule code 8112.99.2000.

[3]Vanadium metal, including waste and scrap. Includes Harmonized Tariff Schedule code 8112.92.7000.

Source: U.S. Census Bureau; data adjusted by the U.S. Geological Survey.

TABLE 5

U.S. IMPORTS AND EXPORTS OF VANADIUM-BEARING ASH AND RESIDUES[1, 2]

(Kilograms unless otherwise specified)

	2017			2018		
Country or locality	Gross weight	Contained weight	Value	Gross weight	Contained weight	Value
Imports for consumption:						
Belgium	--	--	--	128,000	19,700	$282,000
Canada	24,000,000	2,350,000	$12,200,000	23,900,000	2,350,000	57,600,000
Mexico	1,470,000	166,000	2,270,000	2,830,000	429,000	5,790,000
Netherlands	49,900	20,800	54,700	--	--	--
Qatar	--	--	--	79,400	9,590	138,000
Trinidad and Tobago	--	--	--	96,100	5,380	71,200
Total	25,500,000	2,530,000	14,500,000	27,000,000	2,810,000	63,900,000
Exports:						
Belgium	20,000	NA	20,000	338,000	NA	147,000
France	--	--	--	270,000	NA	155,000
Germany	240,000	NA	110,000	176,000	NA	108,000
India	78,900	NA	42,200	118,000	NA	80,600
Italy	--	--	--	19,300	NA	52,100
Korea, Republic of	1,910,000	NA	375,000	389,000	NA	314,000
Mexico	586,000	NA	502,000	804,000	NA	647,000
Ukraine	9,510	NA	13,000	--	--	--
United Arab Emirates	--	--	--	20,000	NA	50,000
United Kingdom	28,000	NA	10,400	905	NA	5,000
Total	2,870,000	XX	1,070,000	2,140,000	XX	1,560,000

NA Not available. XX Not applicable. -- Zero.

[1]Table includes data available through November 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes Harmonized Tariff Schedule codes 2620.40.0030 and 2620.99.1000.

Source: U.S. Census Bureau.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS
VANADIUM CHEMICALS[1, 2]

(Kilograms unless otherwise specified)

	2017			2018		
Material and country or locality	Gross weight	Contained weight	Value	Gross weight	Contained weight	Value
Sulfates:						
Austria	--	--	--	4,200	4,200	$48,500
Canada	--	--	--	--	--	--
China	1,970	1,310	$31,400	7,900	5,070	70,200
Finland	700	700	4,520	--	--	--
Germany	4	2	3,000	--	--	--
Japan	120	75	3,620	160	100	5,130
Netherlands	1,800	1,800	11,600	--	--	--
Total	4,600	3,880	54,200	12,300	9,370	124,000
Vanadates:						
Austria	158,000	103,000	2,390,000	114,000	57,800	2,500,000
China	57,700	47,700	634,000	120,000	97,800	4,400,000
Germany	31,500	12,200	321,000	19,900	7,120	426,000
Hong Kong	--	--	--	5,000	500	160,000
India	100	98	3,110	127	45	11,600
Japan	711	514	28,700	271	168	11,400
Russia	5	1	2,200	--	--	--
South Africa	--	--	--	2,150	1,550	76,100
Taiwan	227,000	186,000	2,860,000	340,000	222,000	9,790,000
United Kingdom	--	--	--	5,700	2,310	86,100
Total	475,000	349,000	6,240,000	608,000	389,000	17,500,000

-- Zero.

[1]Table includes data available through Novmeber 21, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes Harmonized Tariff Schedule codes 2833.29.3000 and 2841.90.1000.

Source: U.S. Census Bureau.

TABLE 7
VANADIUM: WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1, 2]

(Metric tons of contained vanadium)

Country or locality	2014	2015	2016	2017	2018
Brazil	578	3,254 r	4,461 r	5,206 r	5,500
China	54,500 r	51,100 r	45,900 r	45,400 r	40,000 e
Russia	15,125 r	16,000 e	16,000 e	18,000 e	18,000 e
South Africa	21,582 r	17,788	8,163 r	7,959 r	7,700
Total	91,800 r	88,100 r	74,500 r	76,600 r	71,200

[e]Estimated. [r]Revised.

[1]Table includes data available through May 15, 2019. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Canada, Germany, Japan, and the United States, as well as several European countries, continued to recover vanadium from petroleum residues, but available information was insufficient to make reliable estimates.